NTNU
Kunnskap for en bedre verden

Department of Civil and Environmental Engineering

TVM4915 – Hydropower Development
Master’s Thesis

Assessment of Suitability of WEAP for Studies of the Flood Dampening Effects of Reservoirs in Norway

---

Author:
Sajana Pramudith Hemakumara

Supervisor: Professor Tor Haakon Bakken

Date of submission: June 2022

NTNU
Norwegian University of
Science and Technology

Faculty of Engineering

Department of Civil and
Environmental Engineering

M.Sc. Thesis in
Water Resources Modelling and Engineering

- **Candidate: Sajana Pramudith Hemakumara**

Title: Assessment of the suitability of WEAP for studies of the flood dampening effects of reservoirs in Norway

1 BACKGROUND

Floods are globally among the most devastating natural disasters, both in term of lost lives and economic damages. A recent report from Multiconsult (2018) estimated the national, Norwegian losses to be higher than 1 000 mill. NOK annual since 2011 due to flooding, and annual losses in the period 2011 – 2016 to be 4 times higher than in the period 1980 – 2010. The Norwegian hydropower system has a large reservoir capacity and a potential for dampening floods by taking advantage of empty capacity in periods of high runoff. As such, river basins regulated for hydropower benefit from reduced flood peaks and volumes and reduced societal losses during extreme flood events.

A set of different factors determine the ability to dampen floods, such as available storage capacity, location in the basin, and potential for reservoir drawdown prior to the flood are important. For situations with drawdown, the flood prognoses are also important for planning purposes. In multi-purpose reservoirs the balance between drawdown and water storage for other uses also has to be taken into consideration. Flood dampening has recently been used as an argument for hydropower regulation in rivers, and this thesis will evaluate the experience with flood dampening in regulated rivers. This thesis will contribute to better understanding of the role of reservoirs in dampening floods by the use of simulation tools for a selected regulated river basin in Norway.

2 MAIN QUESTIONS FOR THE THESIS

Key questions to be addressed in the thesis are;

1. Perform a national and international literature study to evaluate flood dampening from reservoirs. This part should include the identification of methodological similarities and differences between the performed studies.
2. Configure and assess the performance of WEAP to Garbergelva river basin (which is an unregulated neighbor basin to the highly regulated Nea river basin).
3. Configure WEAP to the highly regulated Nea river basin and perform simulations of runoff and floods in Nea in an unregulated state. Assess the transferability of model parameters from Garbergelva to Nea.
4. Compare the simulated unregulated discharges/floods in Nea river basin with observations of discharges (from the regulated Nea). Select episodes that highlights the effect of reservoirs on discharges/floods.
5. Assess the assumptions, limitations and uncertainties in the methodology and calculations.
6. Outline further work related to the research topic.

3 SUPERVISION, DATA AND INFORMATION INPUT

Professor Tor Haakon Bakken will be the main supervisor of the thesis work. Discussion with and input from colleagues and other research or engineering staff at NTNU, power companies or consultants are recommended, if considered relevant. Significant inputs from others shall be referenced in a convenient manner.

The research and engineering work carried out by the candidate in connection with this thesis shall remain within an educational context. The candidate and the supervisors are therefore free to introduce assumptions and limitations, which may be considered unrealistic or inappropriate in a contract research or a professional engineering context.

4 REPORT FORMAT AND REFERENCE STATEMENT

The report shall be typed by a standard word processor and figures, tables, photos etc. shall be of good report quality, following the NTNU style. The report shall include a summary, a table of content, lists of figures and tables, a list of literature and other relevant references. All figures, maps and other included graphical elements shall have a legend, have axis clearly labelled and generally be of good quality.

The report shall have a professional structure and aimed at professional senior engineers and decision makers as the main target group, alternatively written as a scientific article. The decision regarding report or scientific article shall be agreed upon with the supervisor. The thesis shall include a signed statement where the candidate states that the presented work is his/her own and that significant outside input is identified.

This text shall be included in the report submitted. Data that is collected during the work with the thesis, as well as results and models setups, shall be documented and submitted in electronic format together with the thesis.

The thesis shall be submitted no later than 18th of June, 2022.

Trondheim 15th of January 2022

Tor Haakon Bakken

Tor Haakon Bakken, Professor

DECLARATION

I declare that the work presented in this thesis was carried out by me for the master thesis

“**Assessment of the suitability of WEAP for studies of the flood dampening effects of reservoirs in Norway”**

under the guidance of my main Supervisor Professor Tor Haakon Bakken Department of Civil and Environmental Engineering at Norwegian University of Science and Technology.

Sajana Pramudith Hemakumara
June 2022
Trondheim, Norway

Acknowledgement

I would like to express my sincere gratitude to all who contributed towards making this research study a success. My special thanks go to my main Supervisor Professor
Tor Haakon Bakken from the Department of Civil and Environmental Engineering at Norwegian University of Science and Technology for giving me opportunity to do the research under his supervision and for the immense guidance and encouragement given to me every time towards the success of this thesis by standing always behind me.

I kindly thank Professor. Knut Alfredsen, from the Department of Civil and Environmental Engineering at Norwegian University of Science and Technology for assisting me to this research. It was an immense support and knowledge on hydrology given to me every time I asked a question.

I would also like to express my sincere gratitude to all the Professors and teachers who have taught me during my 2-year master's program in Hydropower Development for all the support given to me during this time frame.

Sajana Pramudith Hemakumara
June 2022
Trondheim, Norway

Abstract

Flooding is a major hazard all over the world. It devastates both human and animal beings and properties. Many flood mitigation options have been intervened to minimize these damages. Reservoirs are constructed for a variety of factors; irrigation, water supply, power generation as well as flood control. Norway is a country that generates power mainly from regulated hydropower systems. It will be interesting to see how flood dampening occurs in a regulated river basin. In this research, the Nea River basin was selected to analyse the dampening of floods by reservoirs. WEAP (Water Evaluation and Planning) software was used to build up and calibrate the hydrological model for unregulated conditions and analyse flood dampening by comparing it with the regulated flows. An adjacent unregulated Garbergelva basin was selected to set up the WEAP model. The calibrated climate parameters were transferred to the Nea model and model was built for unregulated state. It was calibrated at Stokke gauging station (1958-1965) and model was run at Kulset bru station and compared the results with observed discharge. WEAP was assessed to determine the suitability for flood dampening studies in Norwegian climate conditions.

Table of Contents

List of Tables

List of Figures

List of Acronyms

°C	Degrees of Celcius
DEM	Digital Elevation Model
DTM	Digital Terrain Model
Dw	Deep water capacity
EV1	Gumbel Distribution
f	Preferred flow direction
HBV	Hydrologiska Byråns Vattenavdelning
ICOLD	The International Commission on Large Dams
IHA	Indicators of Hydrologic Alteration
Kc	Crop coefficient
Kd	Deep conductivity
Ks	Root zone conductivity
MW	Mega Wott
MWE	Melt Water Equivalent
NOK	Norwegian Krone
NSE	Nash-Sutcliffe Efficiency
NTNU	Norwegian University of Science and Technology
NVE	Norwegian Water Resources and Energy Directorate
PBIAS	Percentage Bias
PCORR	Precipitation Correction
PEST	Parameter ESTimation tool
PET	The Penman-Monteith value for reference crop potential evapotranspiration
R2	Pearsons coefficient of determination
RRF	Runoff resistance factor
SCORR	Snow Correction
SMHI	Swedish Meteorological and Hydrological Institute
Sw	Soil water capacity
SWAT	Soil Water Assessment Tool
WEAP	Water Evaluation And Planning
Z1	Relative storages of the root zone (Initial Z1)
Z2	Relative storages of the deep zone (Initial Z2)

1 Introduction

The main aim of this chapter is to provide the overview, background and problem statement, key research questions, aim, objectives, scope and structure of the research to asses the Suitability of WEAP for studies of the flood dampening effects of reservoirs in Norway.

1.1 Overview

The floods are a major tragedy that will damage both human life and property all over the world. This will lead to dramatic economic damages. In recent times, this has been the headline for many news items. Flash floods, riverine floods and inland floods are among the common types of floods (Earth Networks, 2022). Heavy rainfall, urbanized infrastructure system, snowmelt are several factors involved in the occurrence of floods.

Norway affected by floods annually in the regions around the Norwegian river network, in which the losses initiated from natural causes along with the human actions. A balance is existed between the inflow initiated by rainfall, melted water from snow and inflow from the groundwater storage in Norwegian rivers between and the capacity of the river to transport the inflow further downstream (Roald, 2021). In Norway, it is the combination of rain and snowmelt as metrological factors and urbanized land use as the societal factor that caused the flooding.

Floods can trigger considerable monetary losses, although there are no many human deaths. This have been the dominant cause of economic losses caused by natural disasters in Norway (Roald, 2021). A recent report from Multiconsult (2018) estimated the national, Norwegian losses to be higher than 1 000 mill. NOK annual since 2011 due to flooding, and annual losses in the period 2011 – 2016 to be 4 times higher than in the period 1980 – 2010. During the spring, huge spring floods occur mostly in the large basins in the east and mid-Norway, where agriculture is the most prevalent along the flood plains (Roald, 2021).

1.2 Background and Problem Statement

Norway has been experiencing high intense floods during last 30 years. The pan-European study in which included a historical overview of floods occurring in Norway, mentioned that there has been extreme flooding for the period of 1750 to 1800, 1910 to 1940 and also up to 2014 (Kvittingen, 2020). Reservoirs could be used as a water infrastructure that diminish the flood risk. A large range regulated hydropower systems exist in Norway, where 96% of the total energy consumed in the country comes from hydropower (The Explorer, 2020). Flood damages have been increased at a greater extent in the recent past. Nea is one of the regulatory river basin and it was also subjected to floods. On the other hand, the regulations have decreased the flood damages according to the study which was done to calculate floods Nea-Nidelvvassdraget (Pettersson, 2001). WEAP software has been set for building of hydrological models and flood studies. It will be fascinating to analyse the suitability of WEAP to analyse the flood dampening effects in Nea basin with existing climate conditions (Norwegian climate conditions).

1.3 Research Questions

This key research questions discussed in this dissertation,

- Perform a national and international literature study to evaluate flood dampening from reservoirs. This part should include the identification of methodological similarities and differences between the performed studies.
- Configure and assess the performance of WEAP to Garbergelva river basin (which is an unregulated neighbour basin to the highly regulated Nea river basin).
- Configure WEAP to the highly regulated Nea river basin and perform simulations of runoff and floods in Nea in an unregulated state. Assess the transferability of model parameters from Garbergelva to Nea.
- Compare the simulated unregulated discharges/floods in Nea river basin with observations of discharges (from the regulated Nea). Select episodes that highlights the effect of reservoirs on discharges/floods.
- Assess the assumptions, limitations and uncertainties in the methodology and calculations.
- Outline further work related to the research topic

1.4 Aim

The aim of this thesis is to assess the suitability of WEAP for flood dampening studies in Norway considering the effects of reservoirs.

1.5 Objectives of the Research

The objectives of the thesis in order to deliver the aforesaid research questions, are as cited below

- Selections of an appropriate river basin for the dissertation.
- Selection of an unregulated nearby basin to transfer the similar catchment and climate characteristics.
- Collection of data for the hydrological model (metrological, digital elevation model data, land use data, catchment specific characteristics).
- Schematize the WEAP model, input the climate, elevation and landuse data, and calibrate the model for the observed discharge at a monitoring station, of the unregulated nearby basin.
- Transfer the calibrated parameters to the regulated river baisn and calibrate the model for the aforementioned steps.
- Assess the flood dampening of the reservoirs in the regulated basin;
- Assess the suitability of the WEAP software to the analyse the flood dampening in the specific region of Norway.

1.6 Scope

Nea is a river of length 80km that is located in the Trøndelag country of Norway and some part in Jämtland county of Sweden. The municipalities Selbu and Tydal in Norway and Åre in Sweden falls in this region. It is a river section in the watershed of Nea-Nidelvvassdraget (Wikipedia, 2019). Nea river flows northwards from the Sylsjøen lake in Sweden to through Tydal to Selbusjøen Lake in Trøndelag (Roald, 2021).

Garbergelva was selected as the unregulated river basin (which is adjacent to the Nea basin) that can be used to transfer the parameters to the regulated Nea-Nodelva river basin by calibrating the model in WEAP software. Data collection of metrological data was gathered from Senorge.no, Digital Elevation Model (DEM) Data from Høydedata and ArcMap was used to delineate the catchment and spatial representation of map layers.

Analyse the flood dampening effect of hydropower reservoirs in region snow generated Spring floods and intense rainfall events during Fall.

Assess the performance of WEAP in cold climate river basins

1.7 Structure

The structure of the thesis is as follows,

- Chapter 1 – Introduction
- Chapter 2 – Literature Review
- Chapter 3 – Methodology and Data
- Chapter 4 – Results
- Chapter 5 – Discussion
- Chapter 6 – Conclusion
- Chapter 7 – Recommendation
- Chapter 8 – References

2 Literature Review

The main objective of this chapter is to review the past studies and research that have been carried out related to flood and flood dampening (Globally and Norway), regulated systems in Norway, softwares used to analyse flood dampening and study area focused on this thesis.

2.1 Floods

2.1.1 Global

Flood inundates the land with overflowing of water. It is one of the most devasted hazards that harm life and properties. There is a lot of awareness in the world to mitigate the losses and studies to analyse the occurrence and behaviour of floods.

The flood that occurred in Yangtze–Huai River in 1931 was one of the deadliest floods that happened on earth. It damaged the main cities Nanjing, and Wuhan. The livelihood of people was mainly dependent on agriculture. High-intensity rainfall occurred in April and with the torrential rains followed in July, it was set for a severe flood hazard. In the coming months, a total of 3.7 billion people were killed one of the most densely populated regions in the world. This was later concluded into a dike that breached Lake Gaoyou (History, 2009). Several other floods have occurred in China; happened in central China along Yellow river in 1938 although this was formed by the Government of China in the initial phase of the Second Sino-Japanese War in order to stop the swift progress of Japanese armies, killing 500,000 to 700,000 people (Wikipedia, 2022). Particular floods arose with typhoons and cyclones; in 1991 a deadliest tropical cyclone at a maximum speed of 260 km/h, hit the coastline in the Bay of Bengal killing over 100,000 lives and extensive property damage (Dove & Khan, 1995). Banqiao Dam collapsed due to the sparked Typhoon called Nina in China in 1975, resulted 26,000 deaths and left appropriately 10 million people homeless. The post effect of the disaster was worst as it occurred famine and skyrocketed the death toll up to 100,000 (Yang, Liu, Smith, & Tian, 2017).

2.1.2 Norway

Norway is geographically located 58°N to 71°N and from 5°E to 31°E. North sea is faced by the south coast more than 2000km and Norwegian Sea in the west and the Barents Sea in the northeast. Basins in the coast facing the North Sea and Norwegian Sea have floods triggered by polar front cyclones. Floods caused in Norway is due to snowfall in winter. The large snowmelt floods occurred in 1792, 1860, 1879, 1910, 1916, 1966, 1967, 1995, 2011 and 2013 in South Norway. These floods typically last for nearly a week.

The frequent floods in Norway is due to the combination of rainfall with snow melt. The major floods develop slowly, normally giving time to evacuate for vitims from the exposed part of the flood plain. The large floods were landslide in River Gaula in 1345, Storofsen in 1789 and Storflaumen in 1860 (Roald, 2021).

Flood studies were done considering its past flood history. The first flood model Nea-Nidelva was focasted in 1976. The major floods and landslides occurred in 1927 and 2015 at Telemark region. Telemark flood forecasting model was build considering the flood risk. Flood was occure in 2014 in the town of Voss. Studies carried out to divert the inflow like combination of hydropower and tunnel. Major flood happened in 1995 for Glomma river basin. The flood was caused by a combination of large initial snowpack, a delayed spring and unusual but not extreme precipitation (Killingtveit, 2019). The regions that flood studies conducted by HYDRA research group mentioned in Figure 2-1.

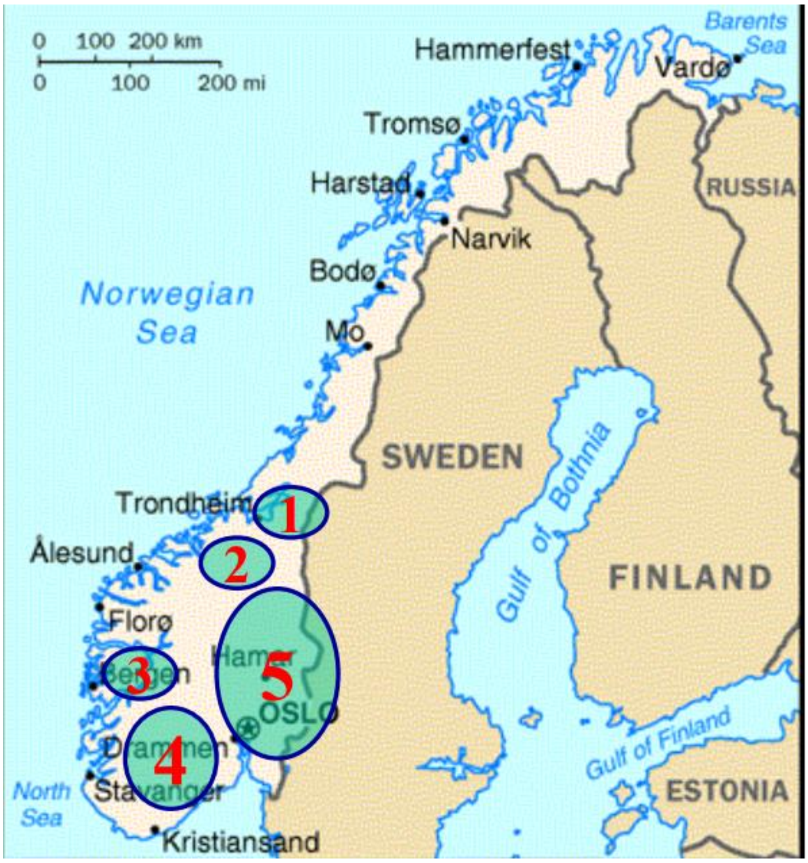


Figure 2-1 : The regions that flood studies conducted by HYDRA (Killingtveit, 2019)

2.2 Flood dampening

The construction of dams plays a huge role in mitigating the occurrence of floods. A reservoir is created in a valley due to the construction of the dam (Public Works Los Angeles Country, 2021). The International Commission on Large Dams (ICOLD) listed the dams based on their purposes as single-purpose and multiple-purpose dams. The majority of the reservoirs are single purpose. The most frequently purpose that the reservoirs have been built is Irrigation. Flood control is the 4th and 2nd largest for single and multiple-purpose reservoirs respectively. The following Figure 2-2 symbolises the summary of 58,713 reservoirs that have been taken into account.

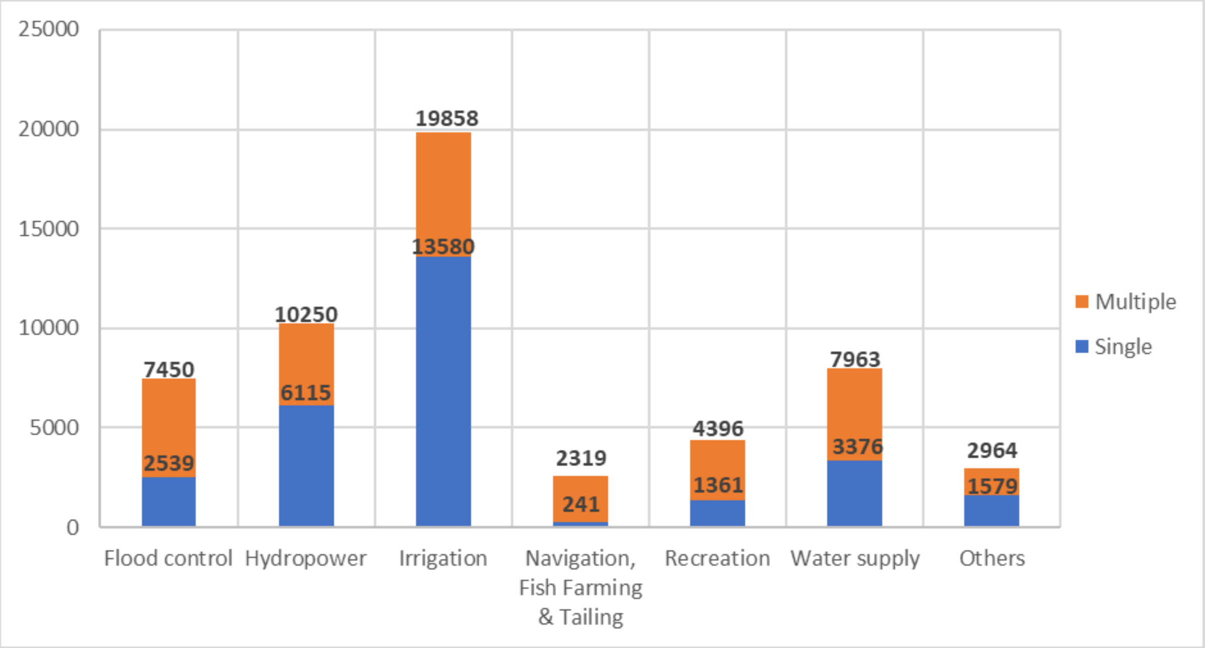


Figure 2-2 : Distribution of dams based on Single and multi-purpose (ICOLD, 2020)

Flood control is a common purpose as one of the most often used function in multipurpose reservoirs. Thus, there is a higher worldwide perspective to mitigate flood in which the reservoirs were not only built for floods.

The amount of water volume that enters a reservoir varies with respect to the volume that flows out of the reservoir. The peak and the time required to achieve the peak of the hydrograph are lowered as a certain volume is stored in the reservoir (Figure 2-3). As a matter, of fact, it has the ability for retaining the flood by dampening the wave of the flood (de Souza, de Carvalho Studart, Lima Neto, & Beserra Campos, 2017).

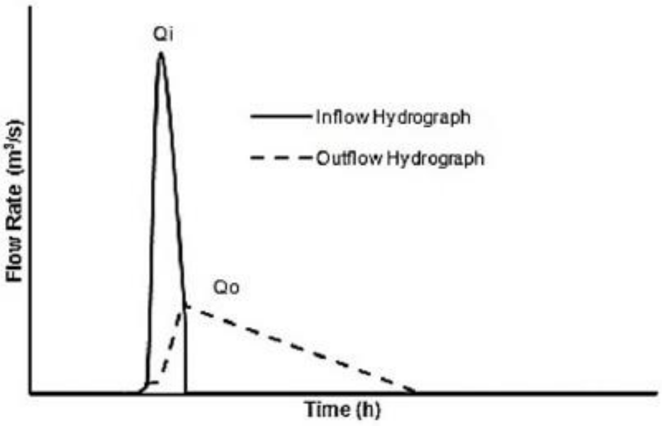


Figure 2-3 : Outflow (Q_o) and Inflow (Q_i) hydrographs in a reservoir (de Souza et al., 2017)

2.2.1 Global

Research and studies have been carried out globally related to flood dampening. A method to design the detention reservoirs was developed by Akan for a variety of return periods using dimensionless equations via numerical modelling (Akan, 1989). Later analysis of the reduction of the flood peaks in a reservoir carried out by using momentum and continuity equations (Garcia-Navvaro & Zorraquino, 1993). A graphical method was proposed considering all morphological parameters of the basin and reservoir in Brazil, were aggregated into a single dimensionless parameter; the Reservoir Damping Index (Φ). It is possible to estimate the damping capacity of the reservoir with this parameter. This can be used for the design of new reservoirs or for the verification of existing reservoir spillways with other methodologies (de Souza, de Carvalho Studart, Lima Neto, & Beserra Campos, 2017).

A case study was done for Severn River in United Kingdom that reviewed the changes in hydrology due the regulations of the river. There was a reduction of annual mean floods by 30% in which the low flows were maintained at a level 22% higher than the Q95 value (Higgs & Petts, 1988). Similar study was concluded for Aragon River in Spain where the impact of the Yesa reservoir during the floods. It was obtained that the floods in the river were in a controllable condition when the level of the reservoir is 50%. The extreme flood was able to be controlled in the range of 50% and 70% of reservoir level (López-Moreno, Beguería, & García-Ruiz, 2002).

Combined H08 and CaMa model were used to evaluate the inundation of the floodplain due to the reservoir operation impacts in Chao Phraya River basin. H08 was an integrated water resources model including a module for operating the reservoir, was linked with CaMa-Flood, a river routing model with interpretation of flood dynamics. The results indicated that volume and depth of flood diminished by 8.6 million m^3 and 40% from the average respectively (Mateo, et al., 2014).

The computational hydrological was built model using MOHID land model in order to simulate the reservoir dampening during floods in the Macaé urban region. The results indicated that the efficiency in flood dampening was 50% higher in the reservoir regions than lower region of the basin which was much urbanised. (Lugon Junior, Tavares, Kalas, Rodrigues, & Wasserman, 2019).

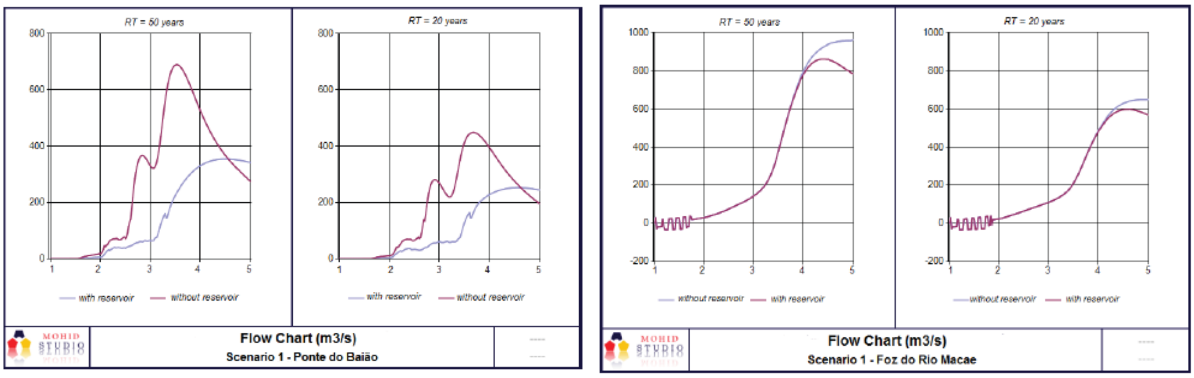


Figure 2-4: Comparison of maximum flow in the reservoir region (left) and lower region (right) of the basin (Lugon Junior, Tavares, Kalas, Rodrigues, & Wasserman, 2019)

2.2.2 Norway

Researches and investigations have been carried out concerning flood dampening for Norwegian climatic conditions. The impact of hydropower systems on floods in the Orkla river was investigated in a master thesis done at NTNU (Norwegian University of Science and Technology). The flood events were simulated considering with and without regulated conditions. Simulation of flow series was done in HBV (which stands for Hydrologiska Byråns Vattenavdelning or Hydrological Agency Water Balance Department) using the gridded precipitation and temperature data from senorge. WEAP model was built up considering the outlet at Bjørset, schematizing the transfers, rivers and reservoirs. The simulation was done next to episodes which were chosen in HBV unregulated and regulated situation. The drawdown effects of reservoirs before a flood event were examined by specifying the number of days to release water before the occurrence of flood. The model outputs have revealed that capacities of reservoirs are enough for retention of flood flows under the assumed realistic filling of reservoir. Distinct release capacities affected the possibility of dampening considerably if the reservoir was full prior to a flood. The Figure 2-5 shows the flood dampening results of Orkla for selected events. The “full” and “observed” peaks were almost ideal up to 1981, Past 1981, the “realistic” and “observed” were equal (Hansen, 2018).

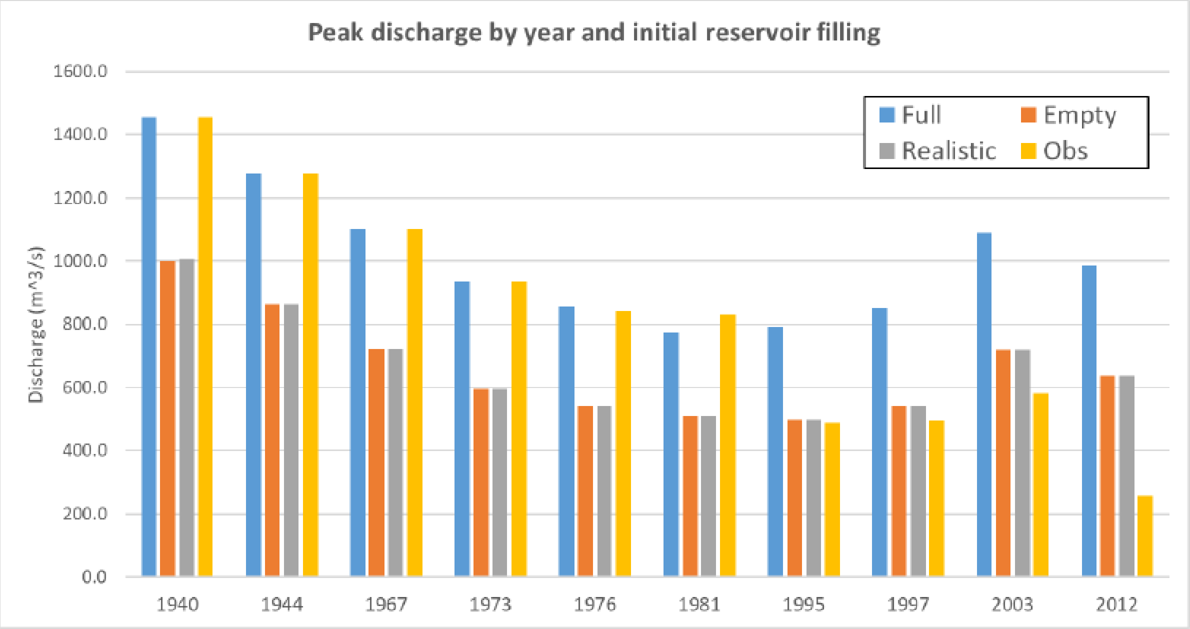


Figure 2-5: The results for flood dampening in Orkla (Hansen, 2018)

Challenges have been faced due to the increased flood damages in the recent past. Energy Norge which is an organisation for the renewable energy industry (Energi Norge, 2021) collaborated with Multiconsult Norge AS which is a leading Norwegian engineering consulting company (Multiconsult, 2021) to illustrate the significance of hydropower regulations on the reduction of flood damages. The impact of reservoir regulation restriction for flood mitigation was calculated. Selbusjøen which is the largest reservoir of Nidelva in Trondheim, obtained new conditions for regulation license in 2014. New requirement was set to maintain the reservoir level at 156.87m which was higher than previously set by the Statkraft. This was applied for the months in summer season after the spring flood has culminated until 1st of October. It was discussed that the flood risk for the buildings around Selbusjøen would rise slightly as an outcome of this shift. For a flood in September 2004, Statkraft estimated that if there had been a restriction of 1.0 meter, the water level would have been 0.9 meters higher. Since there was lack of documentation on how rise in flood water vary in the flood events, an assumption was made that 1-meter restrictions in summer result an increased flood water level of 0.6 meters for all flood events. The Figure 2-6 illustrates the impact of 1 meter restriction of Selbusjøen on the flood events (Glover, Sælthun, & Walløe, 2018).

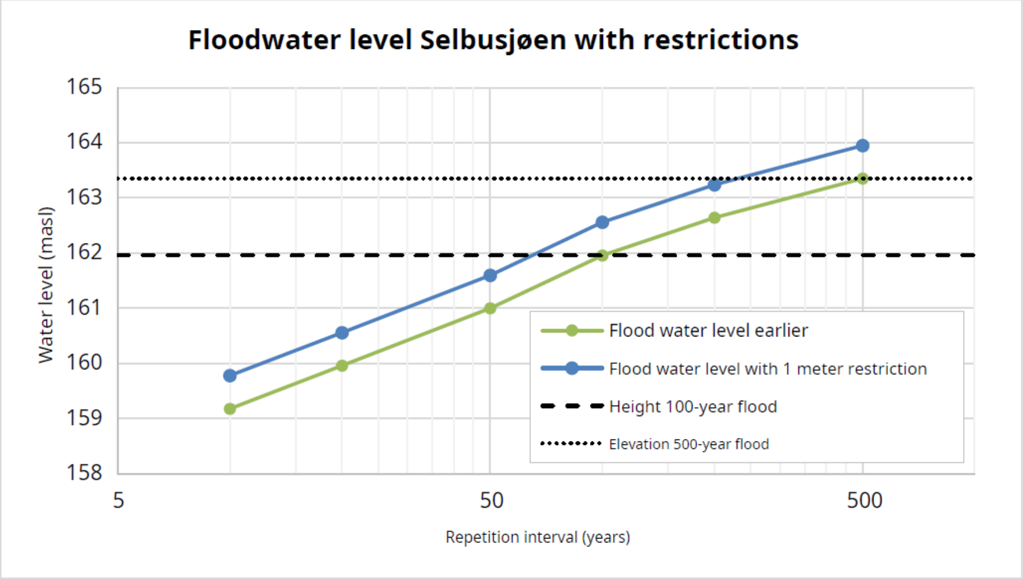


Figure 2-6: The comparison of flood water level restriction in Selbusjøen with return periods (Glover, Sælthun, & Walløe, 2018)

An assessment was done by SINTEF for the hydrological model of HYPE as a tool to support the EU (European) Water Framework Directive in Norway. HYPE is a process-based semi-distributed rainfall-runoff model which has been created at SMHI (Swedish Meteorological and Hydrological Institute) from 2005 onwards. Runoff was calculated for the sub-catchments linked to the waterbody. The Indicators of Hydrologic Alteration (IHA) were found for the selected catchments for the stations Nordsetfoss, Driva ved Grensehølen, Sjursberget and Brattset (Schönfelder, Bakken, Alfredsen, & Adera, 2017).

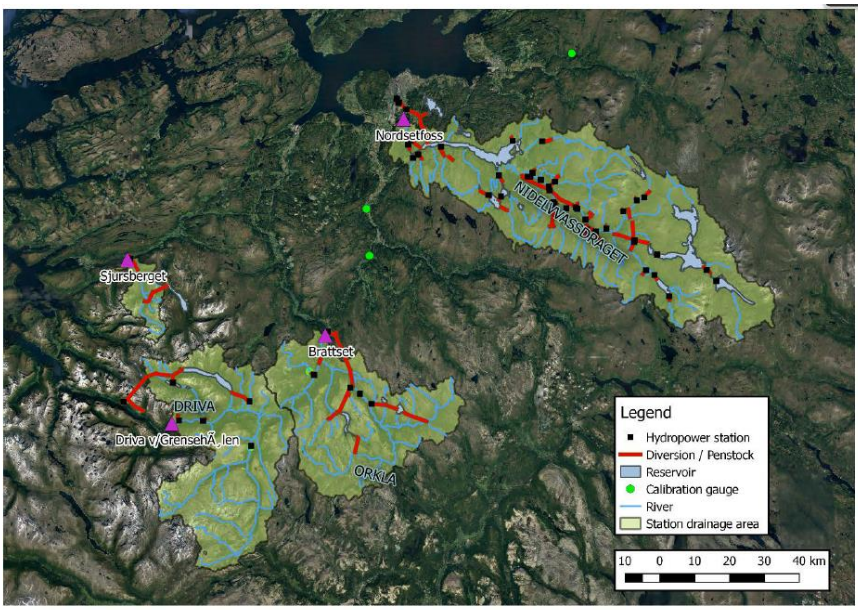
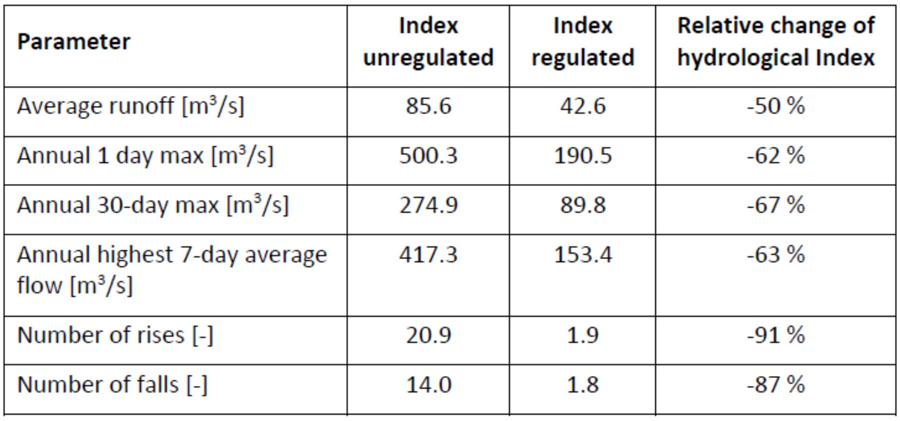


Figure 2-7: The locations of selected sites for calculation of IHA (Schönfelder, Bakken, Alfredsen, & Adera, 2017)

The calculated Hydrological Indices for the gauging station Nordsetfoss in Nidelva is represented in the

Table 2-1.

Table 2-1: Hydrological Indices for Nordsetfoss (Schönfelder, Bakken, Alfredsen, & Adera, 2017)



Parameter	**Index unregulated**	**Index regulated**	**Relative change of hydrological Index**
Average runoff [m³/s]	85.6	42.6	-50 %
Annual 1 day max [m³/s]	500.3	190.5	-62 %
Annual 30-day max [m³/s]	274.9	89.8	-67 %
Annual highest 7-day average flow [m³/s]	417.3	153.4	-63 %
Number of rises [-]	20.9	1.9	-91 %
Number of falls [-]	14.0	1.8	-87 %

The average runoff for the regulated condition at Nordsetfoss was 50% less than that of the unregulated condition. The annual 1 day and 30 day maximum and highest 7 day average discharge were more than 60% less than unregulated condition when considered for regulated scenario (Schönfelder, Bakken, Alfredsen, & Adera, 2017).

A study was done by Norwegian Water Resources and Energy Directorate (NVE) for flood calculation in Nea-Nidelvvassdraget parallel with the Flood Zone Map project. Culmination water level and flow for floods with different return periods were calculated for this watercourse. The reduction of floods with and without regulation in Nea basin was analysed and observed dramatic reduction of the flow for flood events at the Stokke gauging station

Table **2-2**. Flood frequency analysis was performed on data available for Stokke , before regulation, 1915-46, and after the last main regulation of Nesjøen in 1970 (Figure 2-8). The data at Stokke after 1989 was mentioned to be not representative as the operating water flow in the Nedre Nea power plant had commenced to pass by the gauging station (Pettersson, 2001). These results are further compared with my thesis and discussed in the section 5.3.

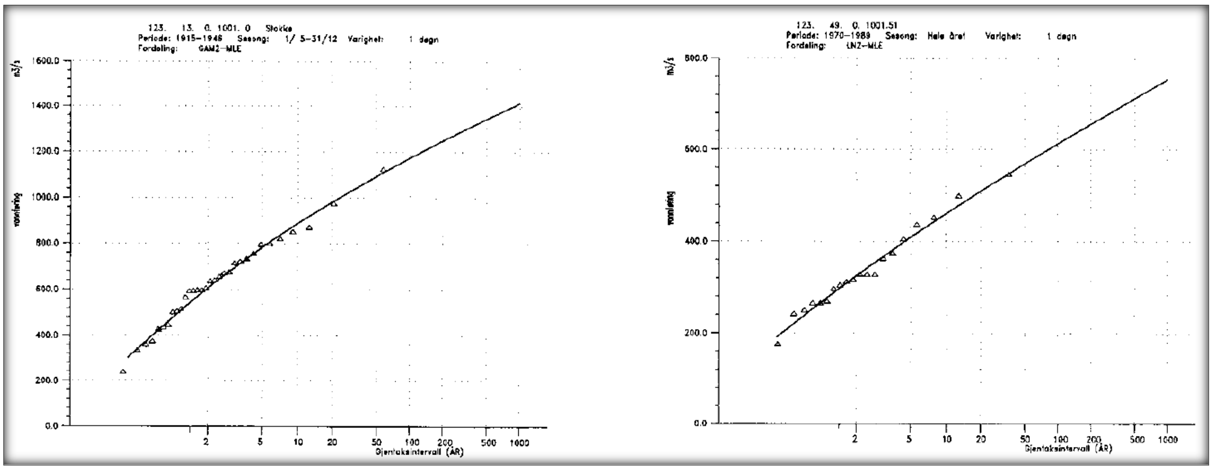
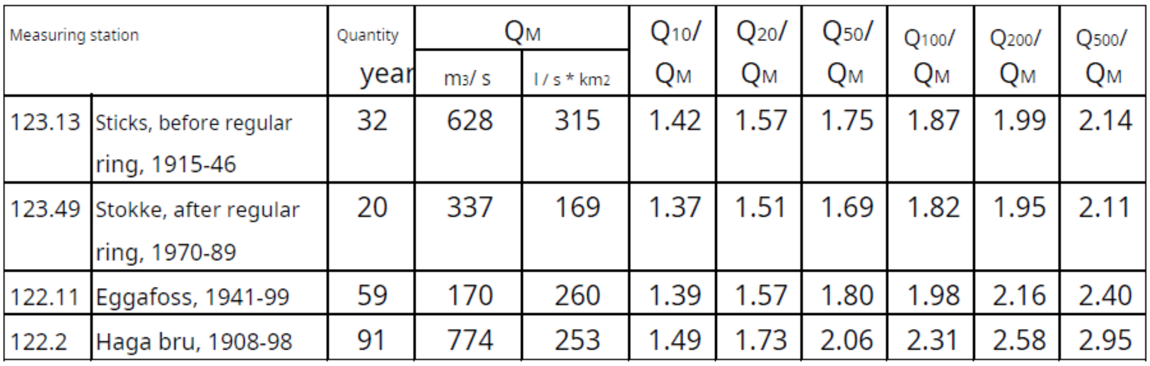


Figure 2-8: The comparison of the flow at Stokke station for return periods in unregulated (left graph) and regulated (right graph) in Nea basin (Pettersson, 2001)

Table 2-2: Flood frequency analysis for 123.13 / 49 Stokke before and after regulation (Pettersson, 2001)



Measuring station		Quantity year	Q_M		Q_{10}/Q_M	Q_{20}/Q_M	Q_{50}/Q_M	Q_{100}/Q_M	Q_{200}/Q_M	Q_{500}/Q_M
			m^3/s	$l/s * km^2$						
123.13	Sticks, before regular ring, 1915-46	32	628	315	1.42	1.57	1.75	1.87	1.99	2.14
123.49	Stokke, after regular ring, 1970-89	20	337	169	1.37	1.51	1.69	1.82	1.95	2.11
122.11	Eggafoss, 1941-99	59	170	260	1.39	1.57	1.80	1.98	2.16	2.40
122.2	Haga bru, 1908-98	91	774	253	1.49	1.73	2.06	2.31	2.58	2.95

2.3 Softwares used for flood dampening

This section explains the brief summary of softwares used for the analysis of flood dampening, such as HBV, WEAP, H08, CaMa, HYPE and MOHID in reference to the section 2.2. The Table 2-3 represents the association of the software in the particular flood dampening study.

Table 2-3: Software's association with the past flood dampening studies

Software/ Tool	Author	Involvement with the software
HBV	(Hansen, 2018)	Simulation of flow series was done in HBV using the gridded meteological data from senorge. Since the model was semi distributed, the simulation was done for 7 separate

Software/ Tool	Author	Involvement with the software
		catchments in Orkala. Using of distributed data helped in creation of a separate HBV model (described as EXCEL HBV) that has the ability to simulate all catchments simultaneously and automatically.
WEAP	(Hansen, 2018)	Schematisation of Orkla catchment was done by including rivers, diversions and reservoirs. Simulation was done for scenarios with and without regulations.
HYPE	(Schönfelder, Bakken, Alfredsen, & Adera, 2017)	A process-based semi-distributed rainfall-runoff model which has been created at SMHI. Simulation of runoff was done for the sub-catchments linked to the waterbody or infrastructures.
H08	(Mateo, et al., 2014)	An integrated water resources model consists of a module for operating the reservoir.
CaMa	(Mateo, et al., 2014)	A river routing model with interpretation of flood dynamics
MOHID	(Lugon Junior, Tavares, Kalas, Rodrigues, & Wasserman, 2019).	The MOHID land module was used. It is a numerical tool designed to simulate hydrodynamic occurrences in river basins. The simulation of discharge and infiltration were modelled with reference to the Curve Number (CN) method, that consists of the distinct soil types and vegetation in the area.

The section 2.2 summarised the flood dampening studies carried out in Norway and globally. Firstly, a hydrological model was built for a particular river basin by inserting data in almost every study. The method of representation of the actual condition or schematisation and its objective was different with respect to the software (Table 2-3). For example, some studies used only one software for their entire research and others interconnected with the softwares. Anyhow, finally, most of the researches compared the unregulated flows with regulated flows.

2.4 Overview of WEAP

WEAP which is also called Water Evaluation And Planning, is a tool for model building policy analysis and planning of water resources. Free license is given for government, non-profit organisations and academic institutions (Wikipedia, 2022). WEAP is attempt to assist the user and does not required the user to be skilful. WEAP has the ability to focus on a broad range of issues such as demand analyses, water conservation, water allocation priorities, groundwater and streamflow simulations, reservoir operations, hydropower generation and energy demands, pollution tracking, ecosystem requirements, and project benefit-cost analyses (Sieber & Purkey, 2015). Software integrates with a range of physical hydrologic processes with the management of demands and installed infrastructure in a smooth and coherent approach. It permits for multiple scenario analysis, involving alternative climate scenarios and land use variations (Yates, Sieber, Purkey, & Huber-Lee, 2005). So, WEAP has an ability to cover almost most of the areas of specification.

A study was done to assess the hydrological components and the available water demand and unmet demand in the sub-catchments of southern zambia. The model was calibrated at R^2 (Pearsons coefficient of determination) of 0.98 and an NSE (Nash-Sutcliffe Efficiency) of 0.83. The model was set for monthly time step (Tena, Nguvulu, Mwelwa, & Mwaanga, 2021).

A research was done to integrate the Soil Water Assessment Tool (SWAT) and WEAP models for management of water resources of Malwathu Oya basin in Sri Lanka. Hydolodical model was built in SWAT and water allocation was tested in WEAP. The results showed that the construction of reservoirs in the Lower Malwathu Oya reservoir and restoration will significantly reduce the demand deficits in the basin (Kaushalya & Hemakumara, 2020).

An evaluation of WEAP model was done subbasins in the Central Rift Valley basin, Ethiopia. The monthly streamflow statistics NSE of 0.80 and R^2 of 0.82 for monthly step. They have compared these statistics with the similar studies.

2.5 Overview of Regulated Systems in Norway

A large range of regulated hydropower systems exists in Norway, where around 90% of the electricity production in the country was generated from hydropower last year (Statkraft, 2021). Hydropower is responsible for most of power supplies in Norway. A unique feature in this hydropower system is the high-level storage capacity of reservoirs. The hydropower production has the ability to become flexible more than 75% times of the entire Europe. The hydropower plants exist most of the regions in Norway Figure 2-9. In the early 2021, 1,681 hydropower plants exist in Norway with an installed capacity of 33,055 MW (ENERGY FACTS NORWAY, 2021). The number of hydropower stations in the early 2021 are 63 and 261 for installed capacities over 100MW and 10-100MW (statista, 2021). The bar chart for the distribution of powerplants with respect to installed capacities illustrated in Figure 2-10.

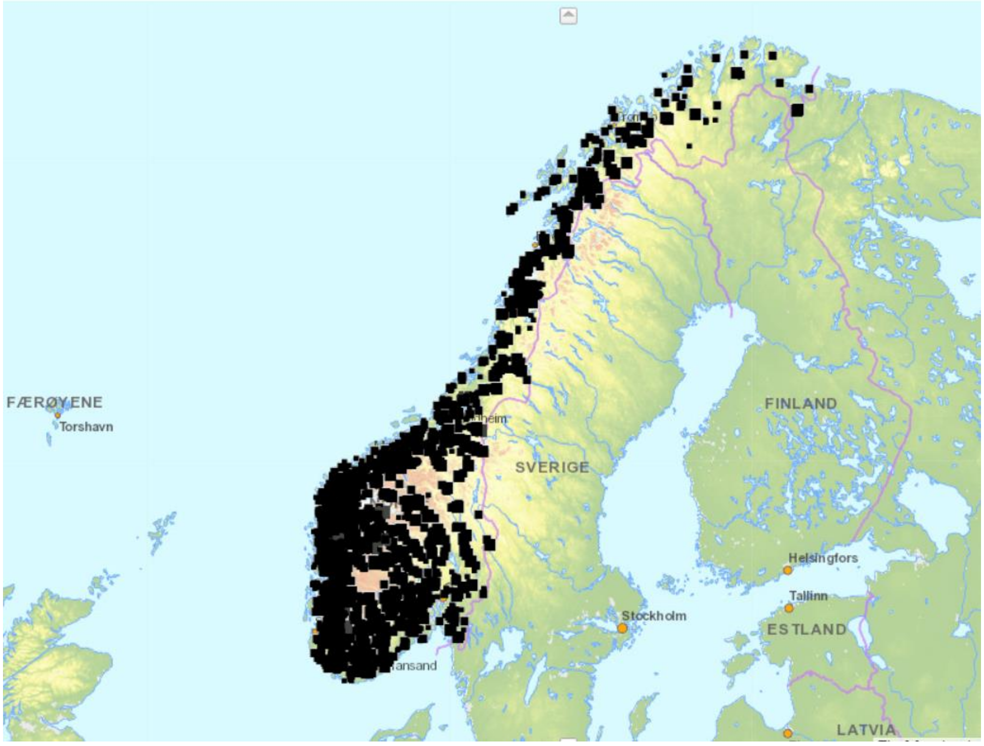


Figure 2-9: The Map for developed hydropower in Norway (NEVINA, 2022)

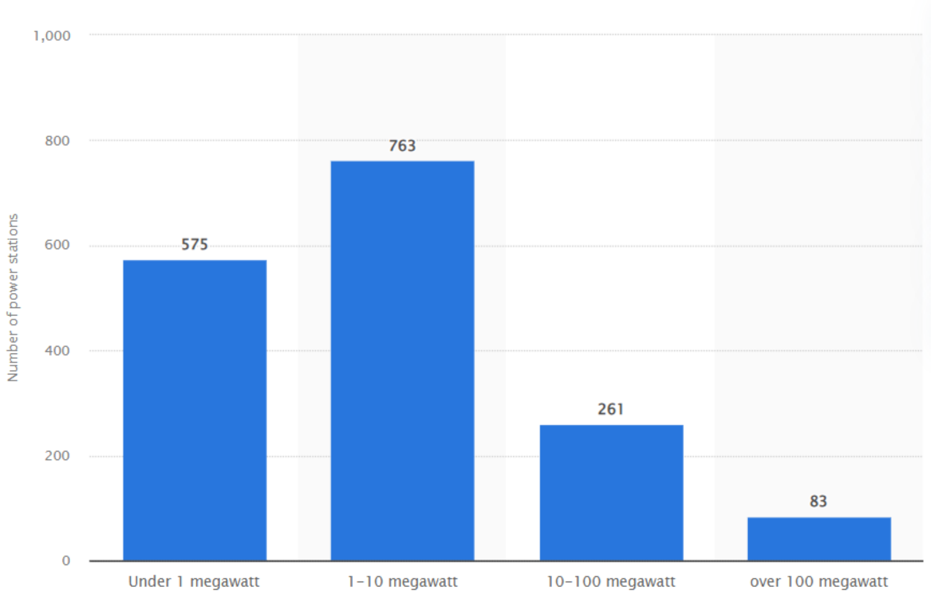


Figure 2-10: The distribution of powerplants with respect to installed capacities (statista, 2021)

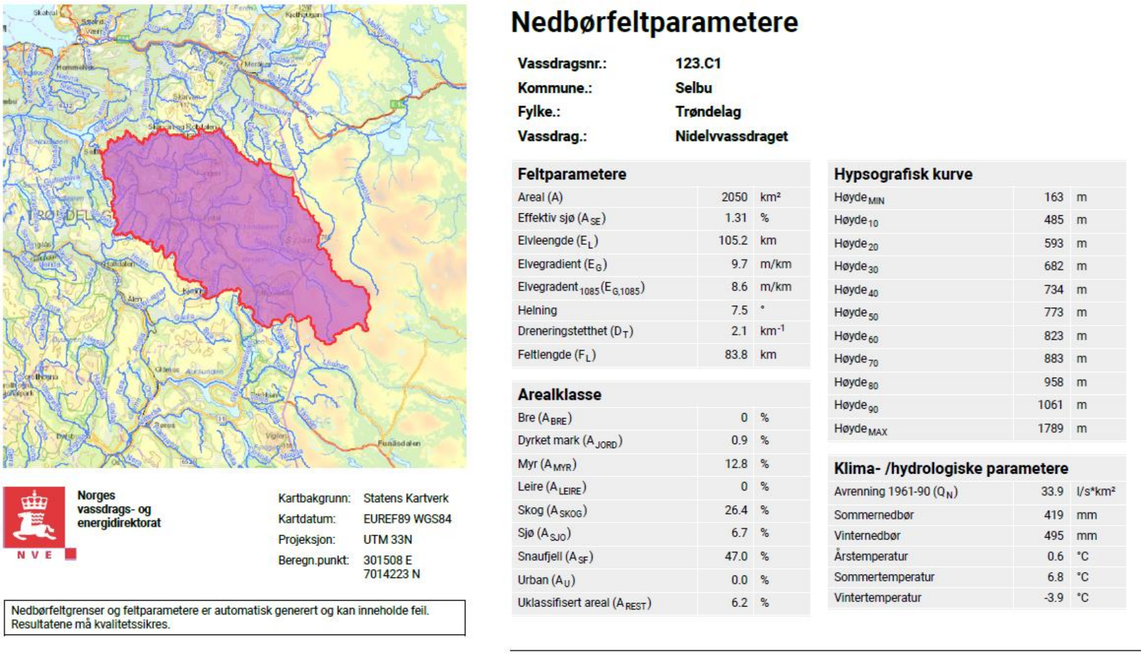
2.6 Study Area

The study area for the “Assessment of the suitability of WEAP for studies of the flood dampening effects of reservoirs in Norway” was selected as the Nea River basin and the adjacent Garbergelva river basin. Nea is a highly regulated river basin with many hydropower systems whilst Garbergelva is an unregulated basin situated adjacent to Nea.

2.6.1 Nea

2.6.1.1 Basic Overview

Nea is a river of length 80km that is located in the Trøndelag country of Norway and some part in Jämtland county of Sweden. The municipalities Selbu and Tydal in Norway and Åre in Sweden falls in this region. It is a river section in the watershed of Nea-Nidelvvassdraget (Wikipedia, 2019). Nea river flows northwards from the Sylsjøen lake in Sweden to through Tydal to Selbusjøen Lake in Trøndelag (Roald, 2021). The catchment area for the farthest outlet (Kulset Bru) is 2050km^2. The region above the Kulset Bru gauging station was considered in this thesis. The catchment characteristics are mentioned below (NEVINA, 2022).



Nedbørfeltparametere

Vassdragsnr.:	**123.C1**
Kommune.:	**Selbu**
Fylke.:	**Trøndelag**
Vassdrag.:	**Nidelvvassdraget**

Feltparametere		
Areal (A)	2050	km²
Effektiv sjø (A_{SE})	1.31	%
Elvleengde (E_L)	105.2	km
Elvegradient (E_G)	9.7	m/km
Elvegradent$_{1085}$ ($E_{G,1085}$)	8.6	m/km
Helning	7.5	°
Dreneringstetthet (D_T)	2.1	km^{-1}
Feltlengde (F_L)	83.8	km

Arealklasse		
Bre (A_{BRE})	0	%
Dyrket mark (A_{JORD})	0.9	%
Myr (A_{MYR})	12.8	%
Leire (A_{LEIRE})	0	%
Skog (A_{SKOG})	26.4	%
Sjø (A_{SJO})	6.7	%
Snaufjell (A_{SF})	47.0	%
Urban (A_U)	0.0	%
Uklassifisert areal (A_{REST})	6.2	%

Hypsografisk kurve		
Høyde$_{MIN}$	163	m
Høyde$_{10}$	485	m
Høyde$_{20}$	593	m
Høyde$_{30}$	682	m
Høyde$_{40}$	734	m
Høyde$_{50}$	773	m
Høyde$_{60}$	823	m
Høyde$_{70}$	883	m
Høyde$_{80}$	958	m
Høyde$_{90}$	1061	m
Høyde$_{MAX}$	1789	m

Klima- /hydrologiske parametere		
Avrenning 1961-90 (Q_N)	33.9	l/s*km²
Sommernedbør	419	mm
Vinternedbør	495	mm
Årstemperatur	0.6	°C
Sommertemperatur	6.8	°C
Vintertemperatur	-3.9	°C

Norges vassdrags- og energidirektorat

NVE

Kartbakgrunn:	Statens Kartverk
Kartdatum:	EUREF89 WGS84
Projeksjon:	UTM 33N
Beregn.punkt:	301508 E 7014223 N

Nedbørfeltgrenser og feltparametere er automatisk generert og kan inneholde feil. Resultatene må kvalitetssikres.

Figure 2-11: The catchment characteristics to the outlet Kulset Bru (NEVINA, 2022)

2.6.1.2 Hydropower system

Nea basin consists of a highly regulated hydropower system. The regulatory system of Nea-Nidelva watercourse illustrated in Figure 2-12. Nea river flows towards the Selbusjøen lake which is 30km long and has a lake area of about 60 km^2. The upstream of the Selbusjøen lake is considered only for the river basin.

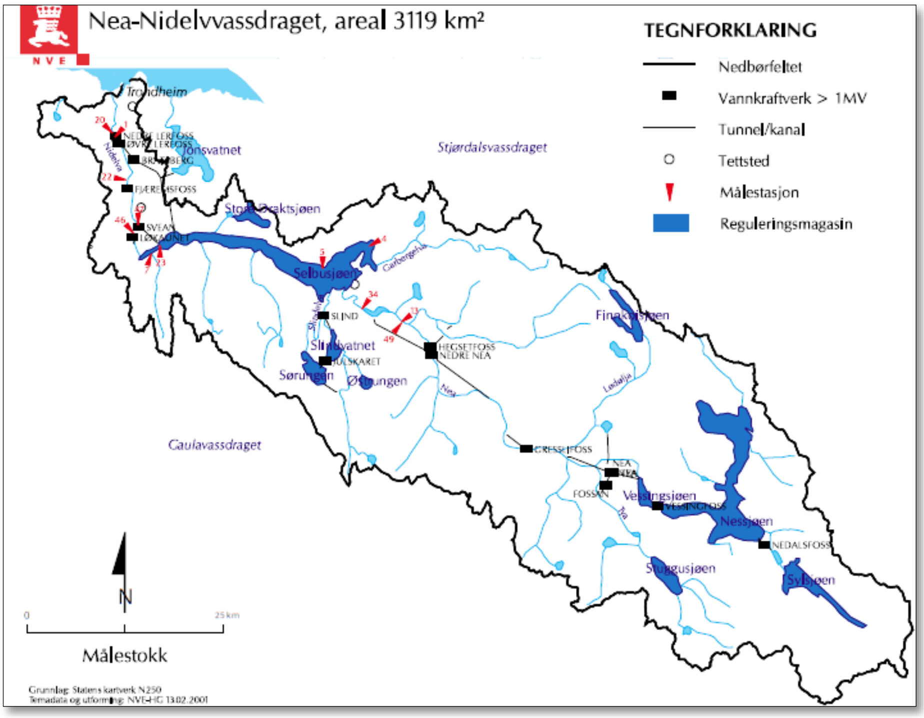


Figure 2-12: The regulatory system for the Nea-Nidelva watercourse (Pettersson, 2001)

Nesjøen is an artificial lake, dammed jointly with Essandsjøen in the period 1968-71 to a very large reservoir. Essandsjøen was regulated as early 1944. Vessingsjøen is also an artificial artificial lake located downstream of Nesjødammen. The most important power plant in the basin which is the Nea power plant, was commenced and operated in 1960. The Tya power plant situated nearby the Nea power plant, that receives water from Finnkoisjømagasinet in Lødølja, a northern river tributary to Nea, and from Stuggusjømagasinet in Tya, a southern tributary of the Nea. Tya power plant is one of Nea power plant's four units. It has an intake in Sellisjøen and thus utilizes a smaller drop height than the other three units. The Fossan power plant was started to operate in 2000 (Pettersson, 2001). The hydropower system for Nea basin is represented in NEVINA as shown Figure 2-13.

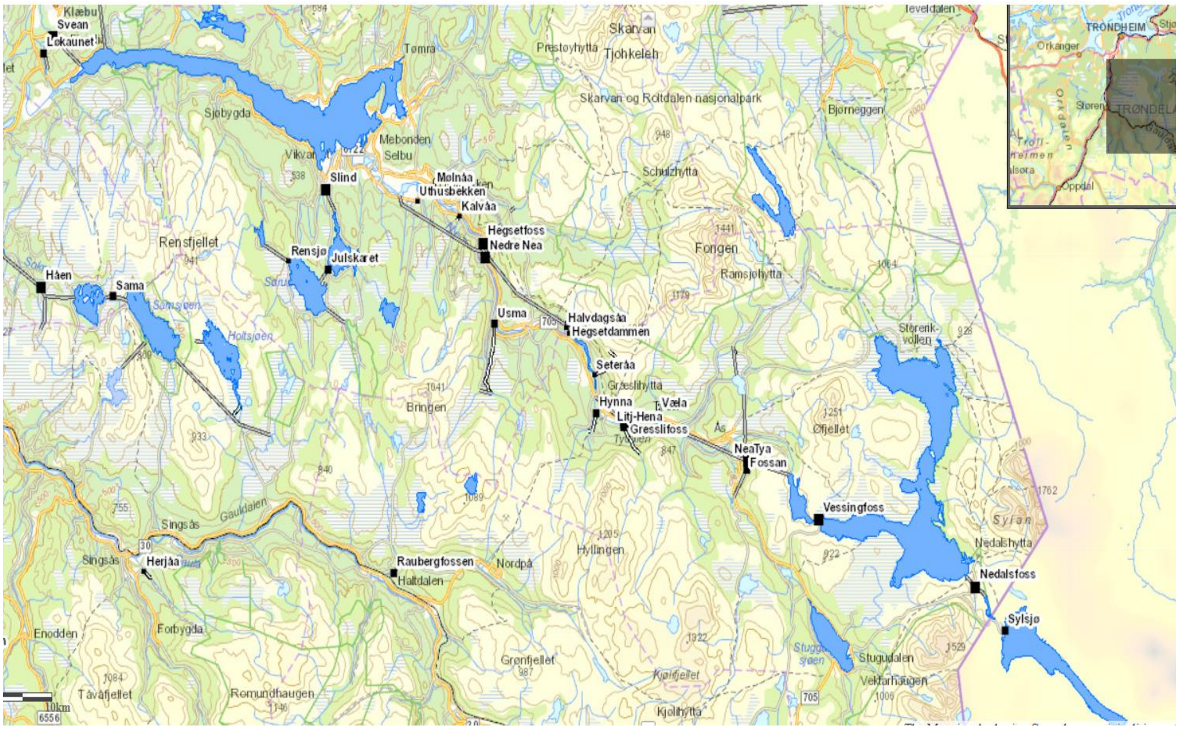


Figure 2-13: The hydropower system for Nea basin (NEVINA, 2022)

2.6.1.3 Hydrometric stations

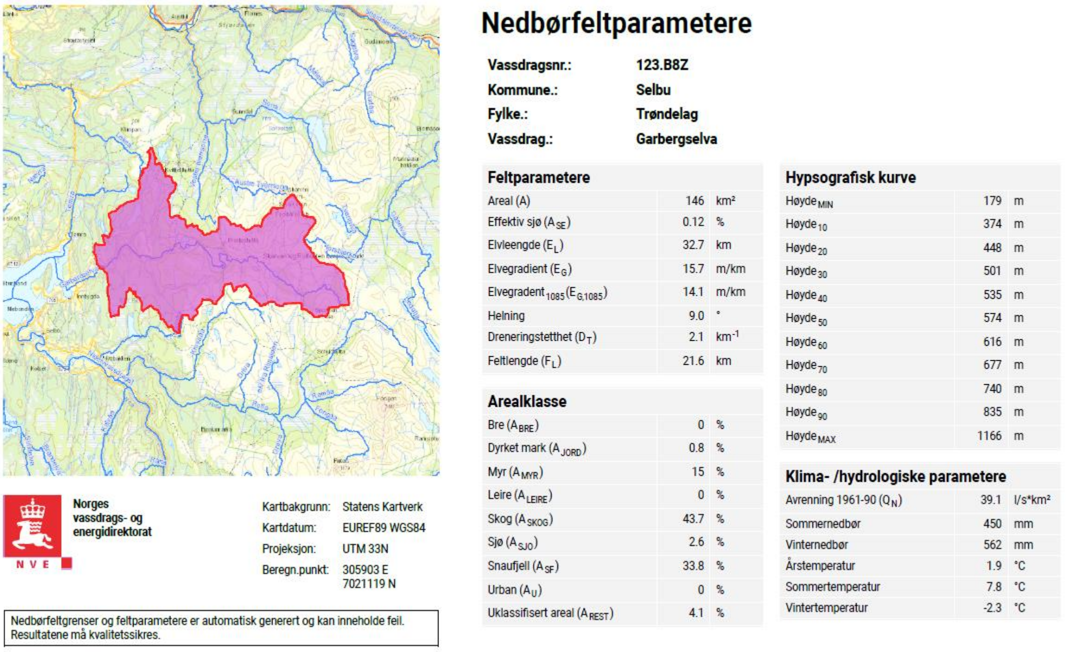
The most important gauging station in the Nea watercourse is the Stokke station. It is the oldest gauging station (123.13) in the basin that has water flow data for the period 1915-1946. This hydrometric station was closed for 20 years, and it was restored later almost the same location. Now it is called 123.49 Stokke limnigraf. It has the precipitation field of 1992 km^2 that represents almost the entire flow of Nea basin. The gauging station consists of data from 1967 to 1990. Later once the operation of the Nea power plant was commensed in 1989, the regulated flow passed through the Stokke station. This resulted closing down of Stokke station and establishing of a new station in the mid-1980s, 123.34 Kulset bridge which is located downstream of the power plant's outlet channel. The flood data of Stokke gauging station was deemed to be good quality (Pettersson, 2001). The locations of Stokke and Kulset bru station denoted in Figure 2-14.

Figure 2-14: The locations of Stokke and Kulset bru station (Seriekart, 2021)

2.6.2 Garbergelva

2.6.2.1 Basic Overview

Garbergelva is an unregulated river basin that comes from the mountain Sprøyta (948 masl) and flows into Selbusjøen lake. It is located in Selbu municipality of Trøndelag country. The river is 30km in length and has a precipitation field of 157 km^2. The watercourse is temporarily protected (Heggstad, 2017). This has a catchment area of 146km^2 for the outlet 123.31.0 Kjeldstad in Garbergelva (NEVINA, 2022). The catchment characteristics are cited below.



Norges vassdrags- og energidirektorat

NVE

Kartbakgrunn:	Statens Kartverk
Kartdatum:	EUREF89 WGS84
Projeksjon:	UTM 33N
Beregn.punkt:	305903 E 7021119 N

Nedbørfeltgrenser og feltparametere er automatisk generert og kan inneholde feil.
Resultatene må kvalitetssikres.

Nedbørfeltparametere

Vassdragsnr.:	123.B8Z
Kommune.:	Selbu
Fylke.:	Trøndelag
Vassdrag.:	Garbergselva

Feltparametere		
Areal (A)	146	km²
Effektiv sjø (A_{SE})	0.12	%
Elvleengde (E_L)	32.7	km
Elvegradient (E_G)	15.7	m/km
Elvegradent$_{1085}$ ($E_{G,1085}$)	14.1	m/km
Helning	9.0	°
Dreneringstetthet (D_T)	2.1	km^{-1}
Feltlengde (F_L)	21.6	km

Arealklasse		
Bre (A_{BRE})	0	%
Dyrket mark (A_{JORD})	0.8	%
Myr (A_{MYR})	15	%
Leire (A_{LEIRE})	0	%
Skog (A_{SKOG})	43.7	%
Sjø (A_{SJO})	2.6	%
Snaufjell (A_{SF})	33.8	%
Urban (A_U)	0	%
Uklassifisert areal (A_{REST})	4.1	%

Hypsografisk kurve		
Høyde$_{MIN}$	179	m
Høyde$_{10}$	374	m
Høyde$_{20}$	448	m
Høyde$_{30}$	501	m
Høyde$_{40}$	535	m
Høyde$_{50}$	574	m
Høyde$_{60}$	616	m
Høyde$_{70}$	677	m
Høyde$_{80}$	740	m
Høyde$_{90}$	835	m
Høyde$_{MAX}$	1166	m

Klima- /hydrologiske parametere		
Avrenning 1961-90 (Q_N)	39.1	l/s*km²
Sommernedbør	450	mm
Vinternedbør	562	mm
Årstemperatur	1.9	°C
Sommertemperatur	7.8	°C
Vintertemperatur	-2.3	°C

Figure 2-15: The catchment characteristics to the outlet Kjeldstad in Garberg (NEVINA, 2022)

2.6.2.2 Hydrometric station

The only available gauging station in Garbergelva river basin is the 123.31.0 Kjeldstad in Garbergelva. The flow data available from 1930 to 2018 in Seriekart.no. The locations of station represented in Figure 2-16.

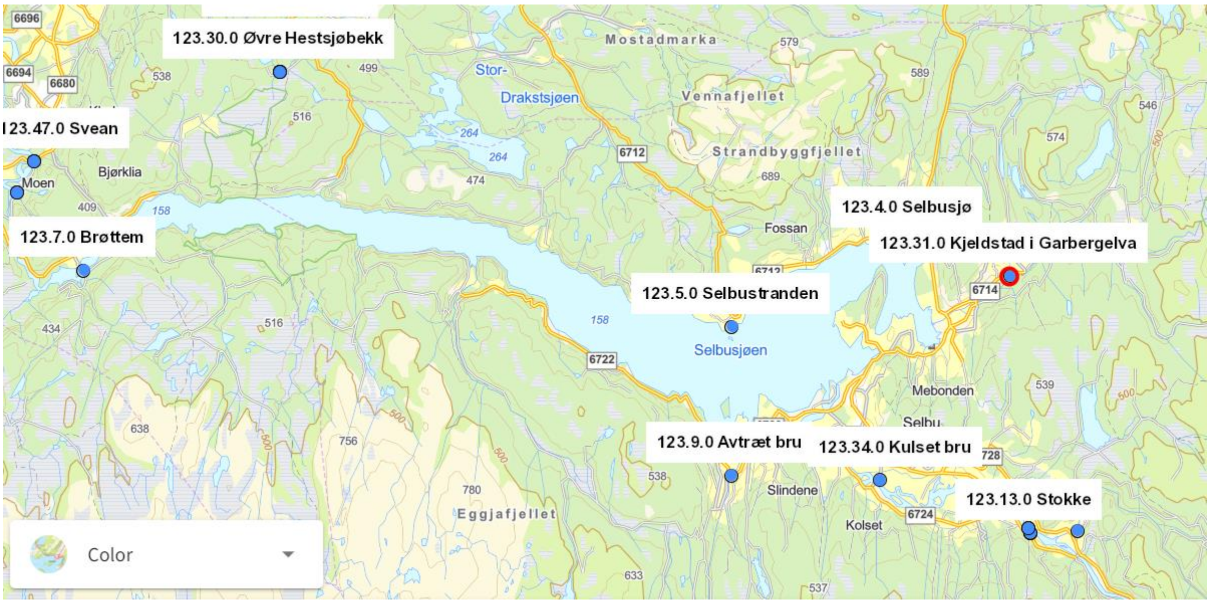


Figure 2-16: The location of Garbergelva station (Seriekart, 2021)

3 Methodology and Data

The methodology of this research categorised in several sections. As a summary, a regulated river basin was selected after performing a national and international literature study to evaluate flood dampening from reservoirs. The data was collected from precipitation and temperature data, Digital Elevation Model (DEM) data, Landuse data and discharge data from various sources (explained in section 3.2). Then the catchment delineation for Nea and Garbergelva basins were done from ArcGIS. After that WEAP software was used for Schematisation, Data Addition for Elevation bands & Model run of Garbergelva Catchment. Calibration was done next, comparing streamflows with observed discharge. Certain calibrated climate parameters were transferred to the Nea WEAP model. Schematisation, Data Addition for Elevation bands & Model run for Nea basin at Stokke station was done. This model was calibrated to the period of 1958-1965. Then the same model was run at Kulset bru station varying only the area for the elevation bands. This model streamflow results were extracted and the effects of flood dampening were highlighted comparing the regulated discharge at Kulset bru. The overview of methodology is illustrated in Figure 3-1.

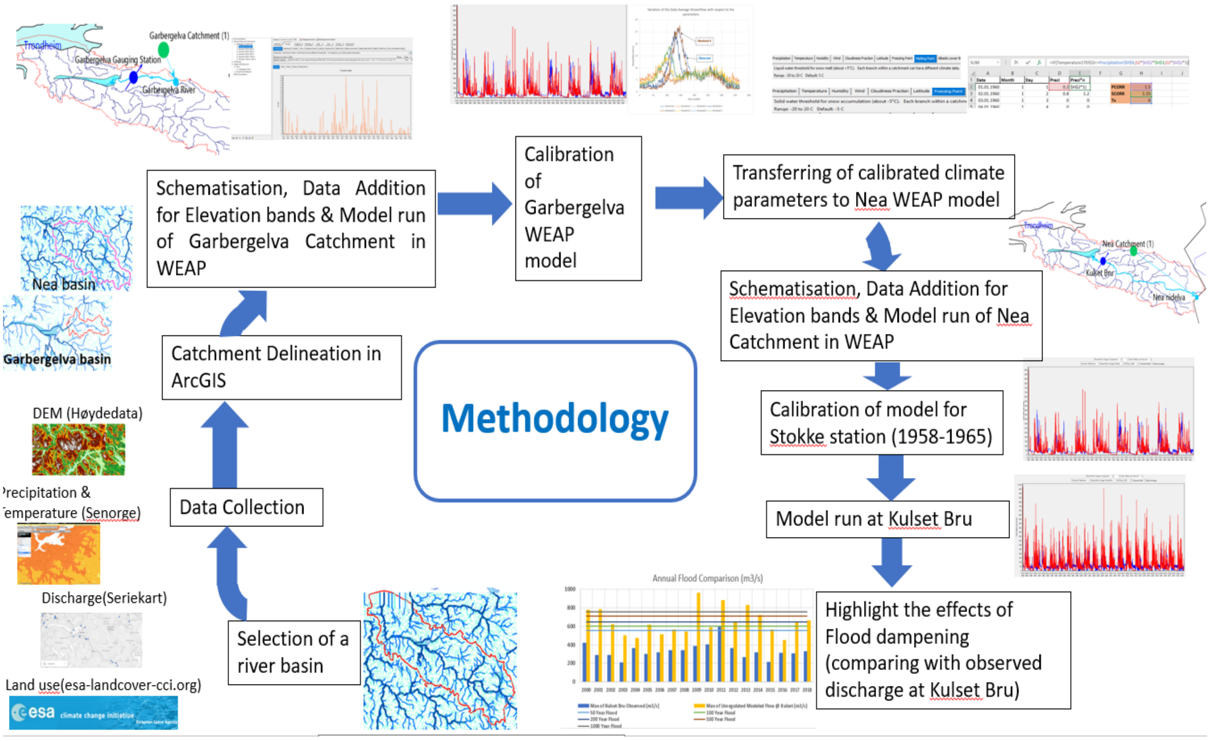


Figure 3-1: The overview of methodology of this research

3.1 Selection of a river basin

The studies carried out in the past (section 2.2), firstly, a hydrological model was built for a particular river basin to analyse the flood dampening effect of reservoirs. A regulatory river system was selected that has an impact on floods with the regulations.

3.1.1 Nea

The study which was done by SINTEF (Schönfelder, Bakken, Alfredsen, & Adera, 2017) concluded with their results, a significant impact of regulation on flood reduction existed in the Nea-Nidelvvassdraget. The research by NVE for the same watercourse also relieved a major decline of flood values in Stokke gauging station due to regulations Figure 2-8. This paved the way of selection Nea river basin as the study region. The catchment generated in NEVINA is shown in Figure 3-3.

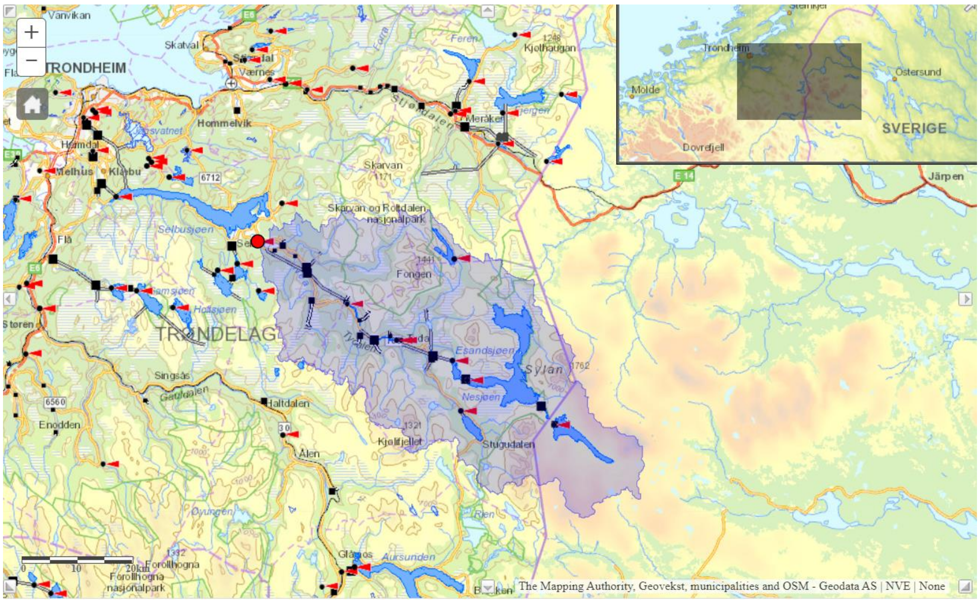


Figure 3-2: The catchment generated in NEVINA (NEVINA, 2022)

3.1.2 Garbergelva

Since the hydrometric stations in Nea basin lacks flow data in unregulated condition, an adjacent river basin with no regulations (watercourse temporally protected). This pave attention to focus on a nearby unregulated Garbergelva river basin. It will be easier to build up the hydrological model and calibrate it for an unregulated basin rather than for a highly regulated basin. The catchment generated in NEVINA is shown in Figure 3-3.

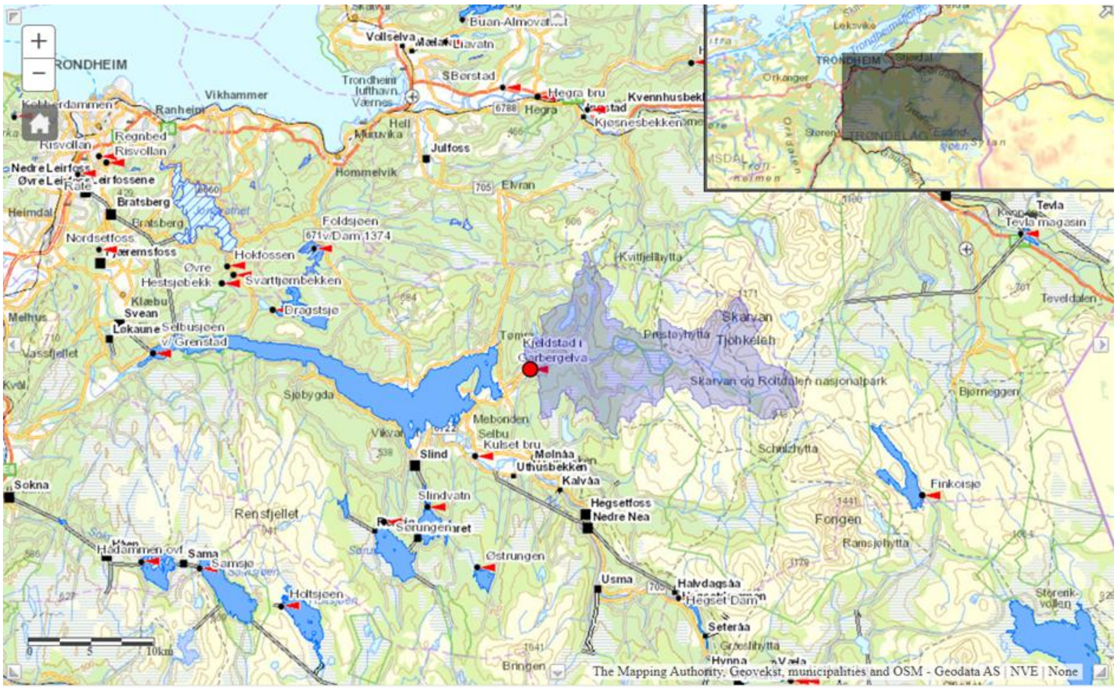


Figure 3-3: View of Garbergelva catchment in NEVINA (NEVINA, 2022)

3.2 Data acquisition

It was required to obtain Meteorological, Digital Elevation Model (DEM) data, Land use and discharge to develop a hydrological model for Nea and Garbergelva river basin.

3.2.1 Meteorological

Data collection of Meteorological data (precipitation and temperature) was gathered from

- Senorge.no – Gridded data where there is no point data available
- klimaservicesenter.no - Point data of precipitation and temperature

The gridded precipitation data data and point data was compared to check the accuracy and relevance in developing the hydrological model. The yearly and monthly comparison of the point and gridded data at Aunet gauge is shown in the following Figure 3-4 and Figure 3-5.

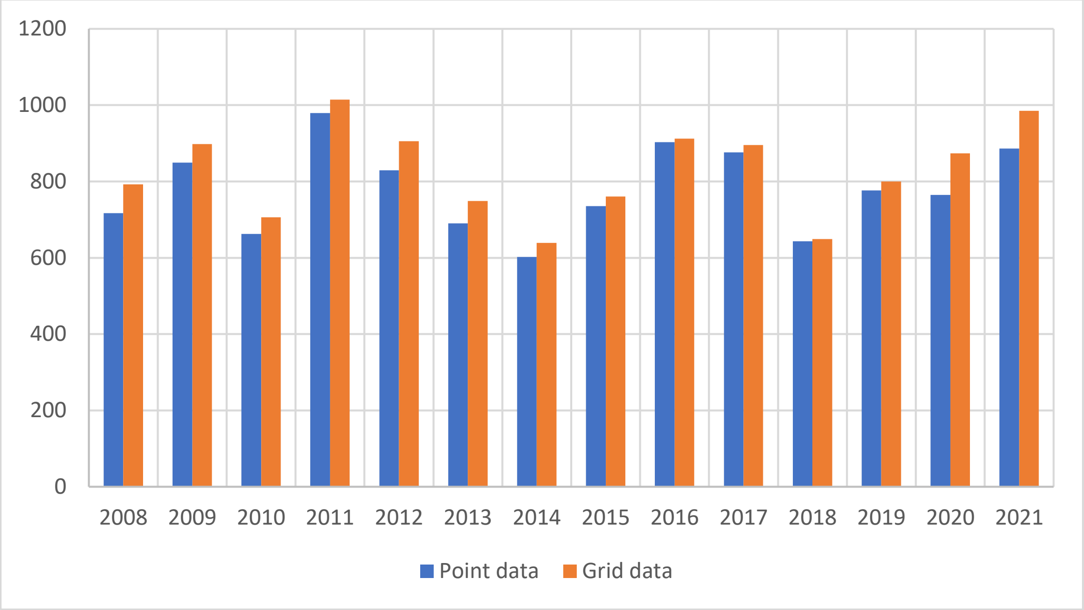


Figure 3-4: Yearly comapariosn of precipitation data at Aunet

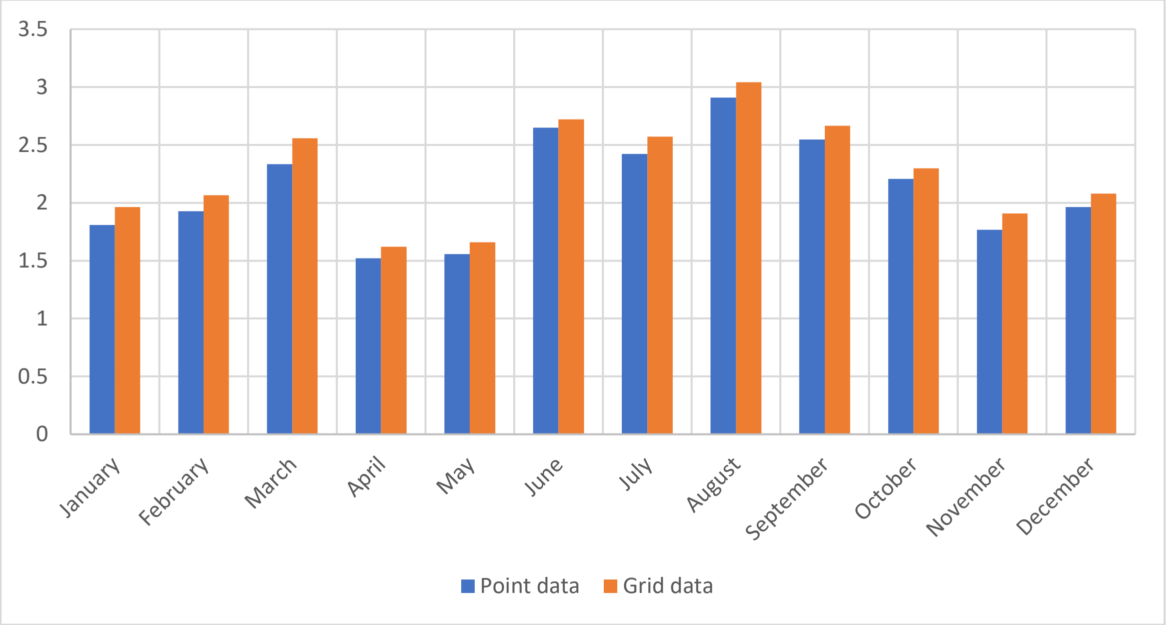


Figure 3-5: Monthly comapariosn of precipitation data at Aunet

The values of gridded data seem to be higher than the point data. Pondering of availability of the data gridded data from Senorge, these data was used in developing the hydrological model for the river basins. The gridded precipitation data were collected at the centre of the catchment for Garbergelva, Stokke and Kulset bru.

The temperature data was gathered for several elevation bands for the catchments separately. The main reason for that is the variation of temperature with the elevation. The elevations at which the temperature data was collected for the catchments are represented in the following Table 3-1 and locations are represented in the Figure 3-6.

Table 3-1: Elevations at which the temperature data was collected in Senorge

Elevation Bands (m)	Garbergelva (m)	Stokke (m)	Kulset Bru (m)
0 – 200	170	180	180
200 – 400	300	300	300
400 – 600	500	500	500
600 – 800	700	700	700
800 – 1000	900	900	900
1000 – 1200	1054	1100	1100
1200 – 1400		1350	1350
1400 – 1600		1505	1505
1600 – 1800		1685	1685

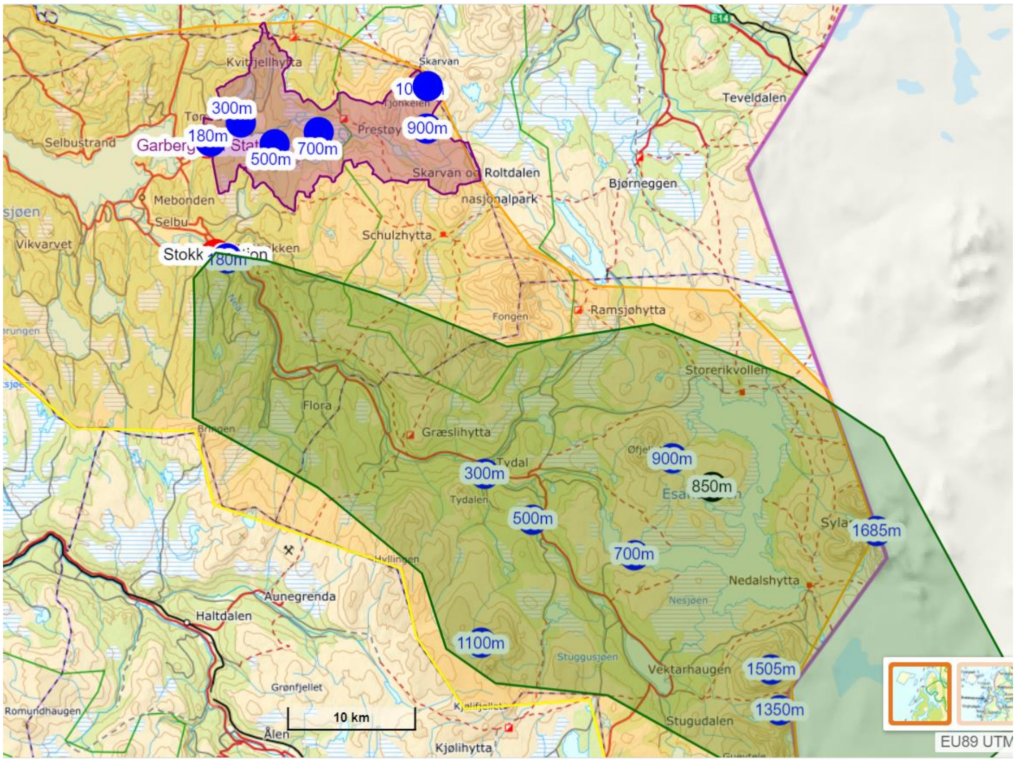


Figure 3-6: Locations in which temperature data collected for the catchments displayed in norgeskart

The same temperature data of Stokke was taken for considering Kulset Bru as well due to the small difference in areas (around 60 km^2) between the catchments.

3.2.2 Digital Elevation Model (DEM)

Digital Elevation Model (DEM) Data was downloaded from Høydedata. DTM10 (10-meter resolution data) was the resolution of data. ArcMap was used to delineate the catchment and spatial representation of map layers. The elevation data relevant to the unregulated Garbergelva and regulated Nea river basins were extracted by clipping tool in ArcGIS.

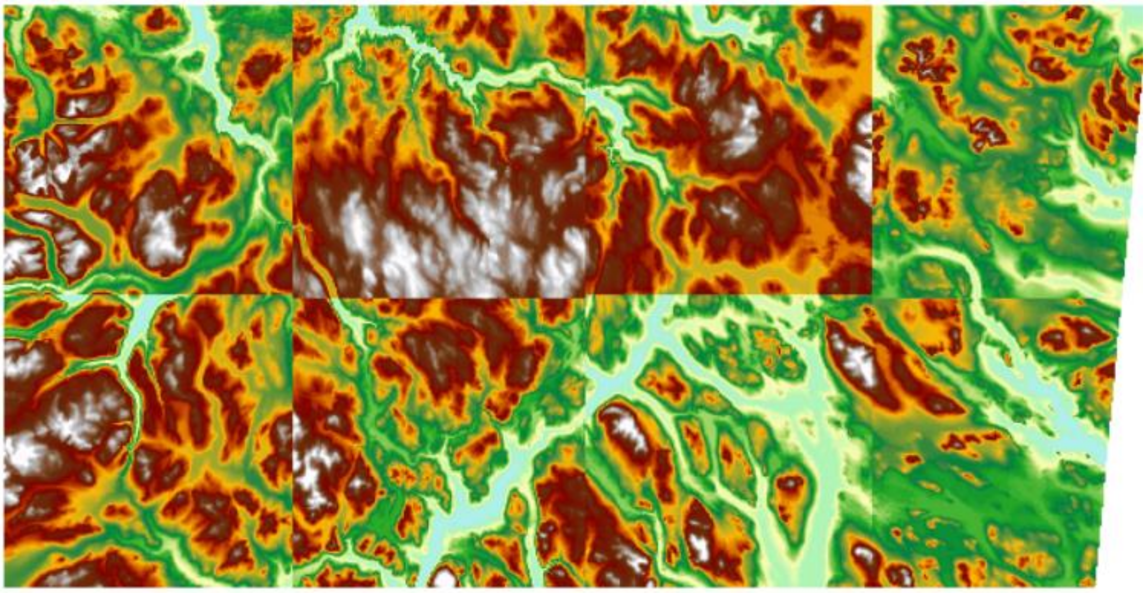


Figure 3-7: DEM data from Høydedata (Høydedata, 2021)

3.2.3 Land use

Land cover maps were downloaded from ESA-CCI-LC data set of version 2.0.7 for 2015 (Figure 3-8). The data set consists of land classes as mentioned in Figure 3-9.

The land cover data were extracted for the unregulated Garbergelva and regulated Nea catchments in ArcGIS.

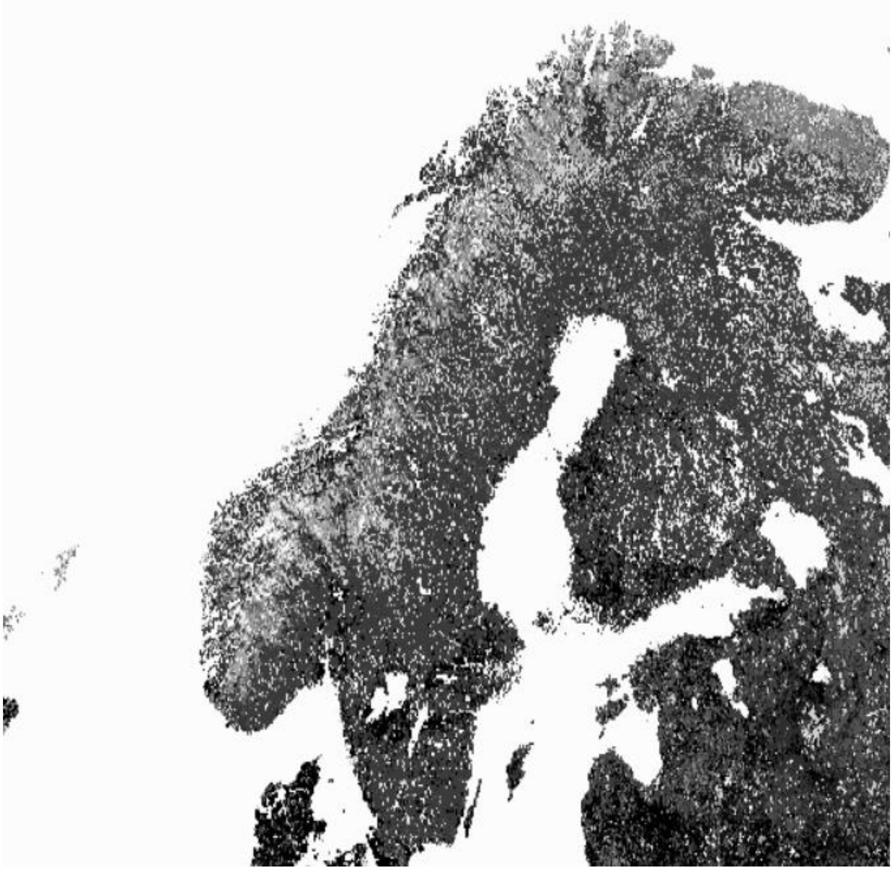
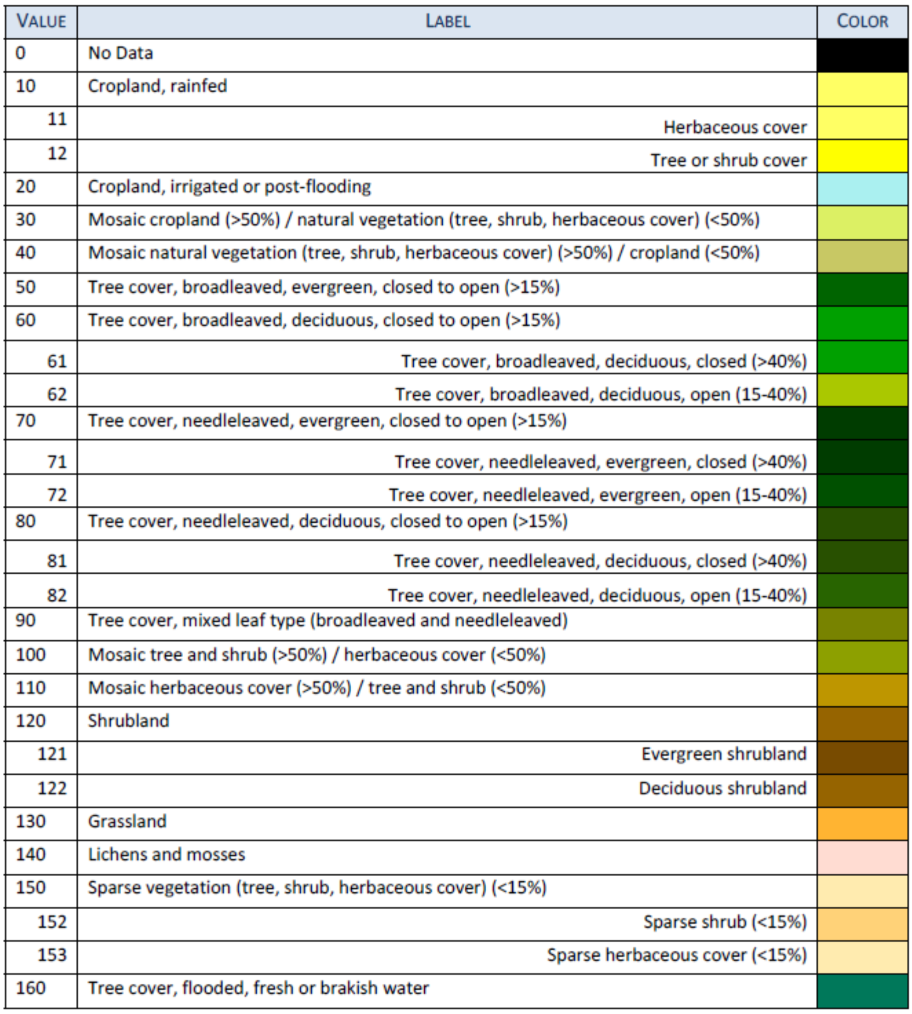


Figure 3-8: ESA-CCI-LC data set of version 2.0.7 for 2015 (climate change initiative Land Cover, 2015)

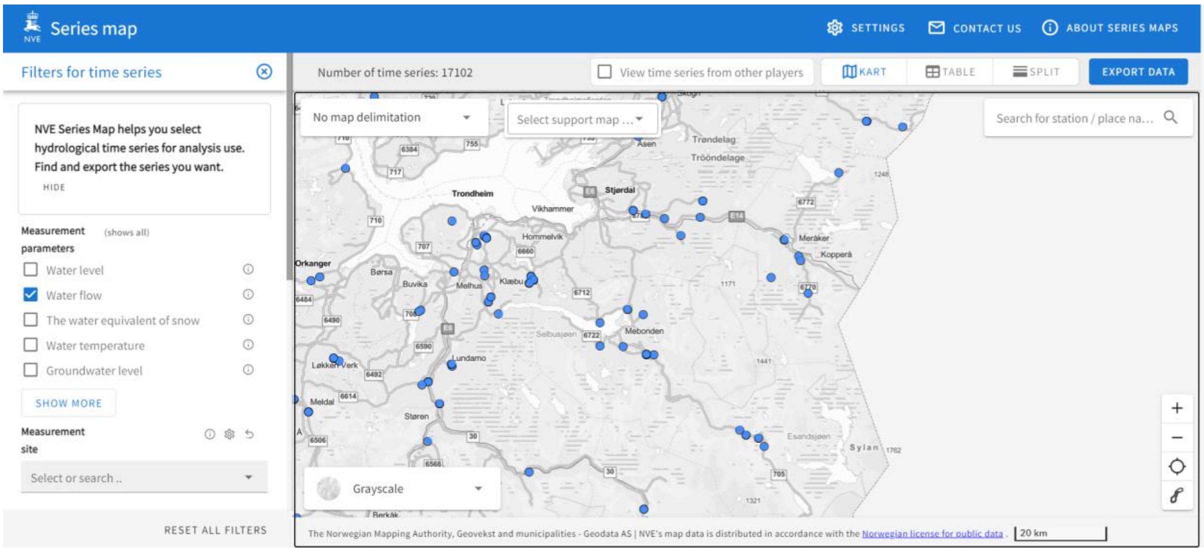


VALUE	LABEL	COLOR
0	No Data	⬛
10	Cropland, rainfed	🟨
11	Herbaceous cover	🟨
12	Tree or shrub cover	🟨
20	Cropland, irrigated or post-flooding	🟦
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)	🟨
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)	🟨
50	Tree cover, broadleaved, evergreen, closed to open (>15%)	🟩
60	Tree cover, broadleaved, deciduous, closed to open (>15%)	🟩
61	Tree cover, broadleaved, deciduous, closed (>40%)	🟩
62	Tree cover, broadleaved, deciduous, open (15-40%)	🟩
70	Tree cover, needleleaved, evergreen, closed to open (>15%)	🟩
71	Tree cover, needleleaved, evergreen, closed (>40%)	🟩
72	Tree cover, needleleaved, evergreen, open (15-40%)	🟩
80	Tree cover, needleleaved, deciduous, closed to open (>15%)	🟩
81	Tree cover, needleleaved, deciduous, closed (>40%)	🟩
82	Tree cover, needleleaved, deciduous, open (15-40%)	🟩
90	Tree cover, mixed leaf type (broadleaved and needleleaved)	🟩
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	🟩
110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	🟧
120	Shrubland	🟫
121	Evergreen shrubland	🟫
122	Deciduous shrubland	🟫
130	Grassland	🟧
140	Lichens and mosses	🟥
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)	🟨
152	Sparse shrub (<15%)	🟧
153	Sparse herbaceous cover (<15%)	🟨
160	Tree cover, flooded, fresh or brakish water	🟩

Figure 3-9: Legend of global land cover maps based on land cover classes (Quick user guide of the Land Cover State products in GTiff and NetCDF formats, 2015)

3.2.4 Discharge

Discharge data was gathered from Seriekart.no which uses NVE series map to select flow data of respective gauging stations with regard to a time series. Flow data for 123.31.0 Kjeldstad in Garbergelva and 123.34 Kulset bru were collected from this webisite. But the discharge data was not available in this site so that it was obtained by the aid of Professor Knut Alfredsen at NTNU.



NVE Series Map helps you select hydrological time series for analysis use. Find and export the series you want.

Measurement parameters (shows all)

- ☐ Water level
- ☑ Water flow
- ☐ The water equivalent of snow
- ☐ Water temperature
- ☐ Groundwater level

Measurement site: Select or search ..

Number of time series: 17102

☐ View time series from other players

No map delimitation

Select support map ...

Search for station / place na...

Grayscale

The Norwegian Mapping Authority, Geovekst and municipalities - Geodata AS | NVE's map data is distributed in accordance with the Norwegian license for public data.

Figure 3-10: The interface of Seriekart which dicharge available to download

3.3 Delineating Catchment using ArcMap

The catchments of the unregulated Garbergelva river basin at Kjeldstad in Garbergelva, the regulated Nea basin at Stokke limnigraf and Kulset bridge were delineated using ArcGIS. The DEM was exported to ArcGIS, remove errors by filling voids, generated the flow direction map, flow accumulation depicting number of upstream cells for each grid cell and segmentation of streams were followed up to delineate the cathments.

3.3.1 Garbergelva

The catchment delineated at Kjeldstad in Garbergelva and extracted the elevation data for elevation branches

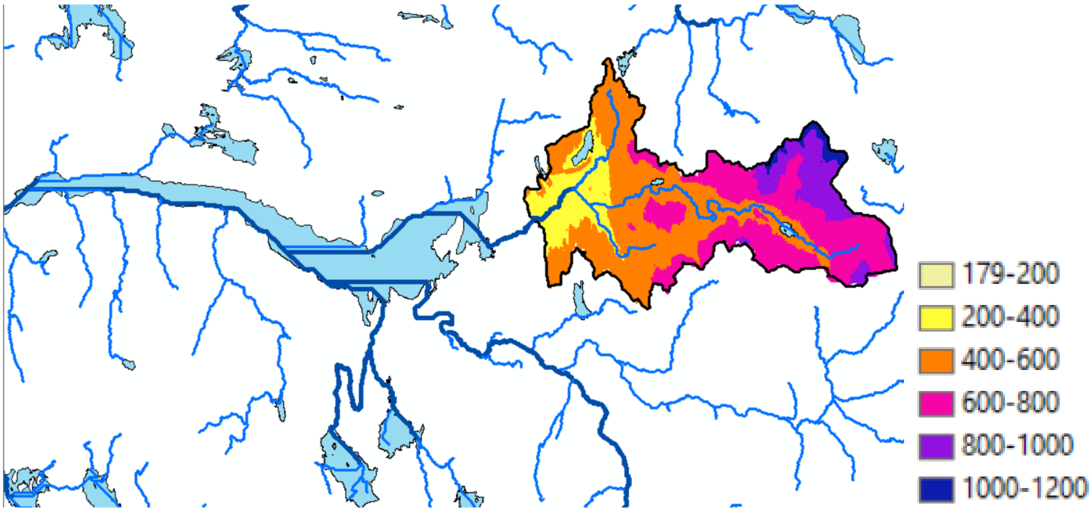


Figure 3-11: The reclassification of the Garbergelva DEM for elevation bands

3.3.2 Stokke

The catchment delineated at Stokke limnigraf and extracted the elevation data for elevation branches

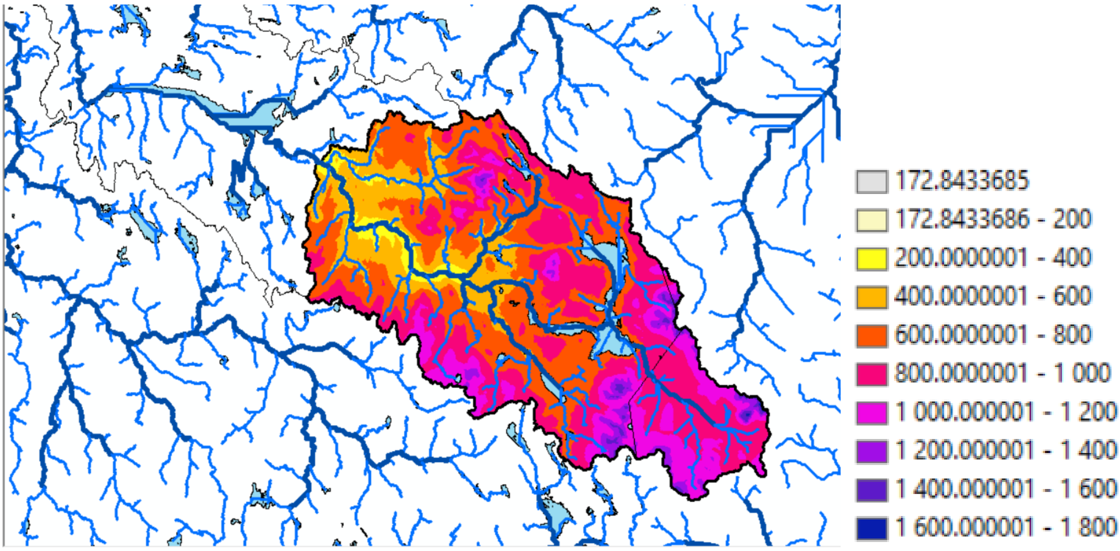


Figure 3-12: The reclassification of the Stokke DEM for elevation bands

3.3.3 Kulset Bru

The catchment delineated at Kulset Bru and extracted the elevation data for elevation branches

.

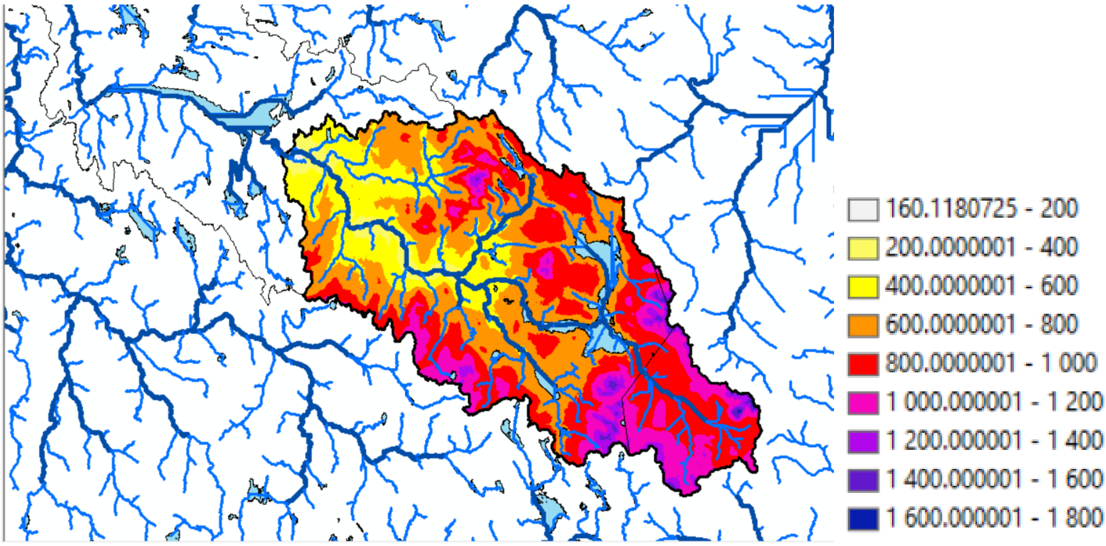


Figure 3-13: The reclassification of the Kulset Bru DEM for elevation bands

3.4 Developing the hydrological model in WEAP

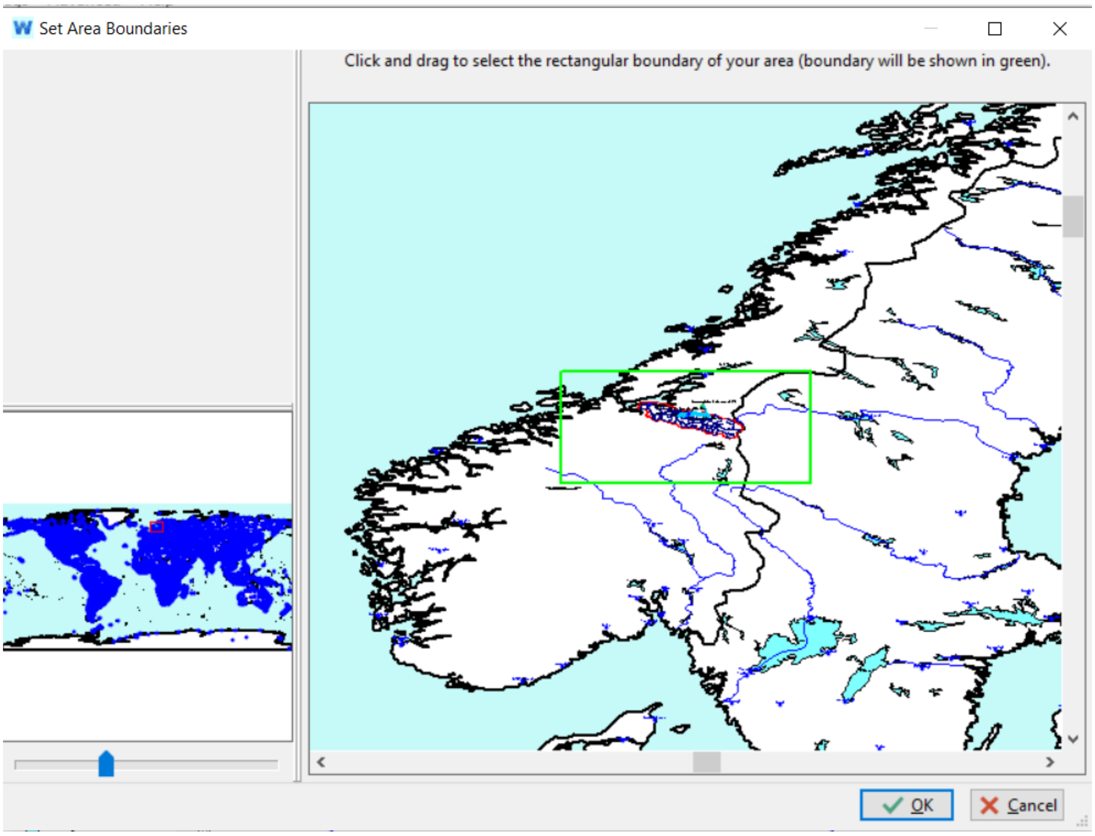
Developing of the hydrological model for catchments using particular software was supposed to be task in this step. The section 2.3 mentioned variety of softwares used to build up a hydrological model. WEAP software was used to develop the hydrological model as an objective of this study.

3.4.1 Garbergelva

Nea river basin consists of a large number of regulated systems as mentioned in section 2.6.1.2. Unregulated observed discharge data is limited in gauging stations in Nea basin. This makes a hydrological model somewhat complicated for calibration as stated in section 3.1.2. Also, developing and calibrating a hydrological model for an unregulated basin makes it easier to follow up building WEAP models for other two catchments.

3.4.1.1 Schematisation

The first step that a modeler should follow in the course of developing a WEAP model is the addition of data variables by defining the geographic boundaries.



Click and drag to select the rectangular boundary of your area (boundary will be shown in green).

Figure 3-14 : Definition of geographical area boundaries

The addition of climate, elevation data and land-use data for the respective catchment is an automated process in the recent WEAP software versions in which these data can be downloaded by switching into the "Catchment Delineation Mode". However, this mode is not available in locations above the Telemark region in Norway. Thus, it has to be done manually for the Garbergelva catchment.

The shapefiles of the river network and basin for Nea Nidelva were added as an initial step of generating the WEAP variables. Next, the river network for Garbergelva catchment was drawn by tracing the shapefile. Thereafter "Catchment" and "Streamflow Gauge" nodes were added to input catchment characteristics and streamflow data respectively (Streamflow Gauge was placed on the WEAP river). A Runoff/Infiltration link was added from the Catchment node to the River to define the flow along the Garbergelva river. The schematic view is shown in Figure 3-15 below.

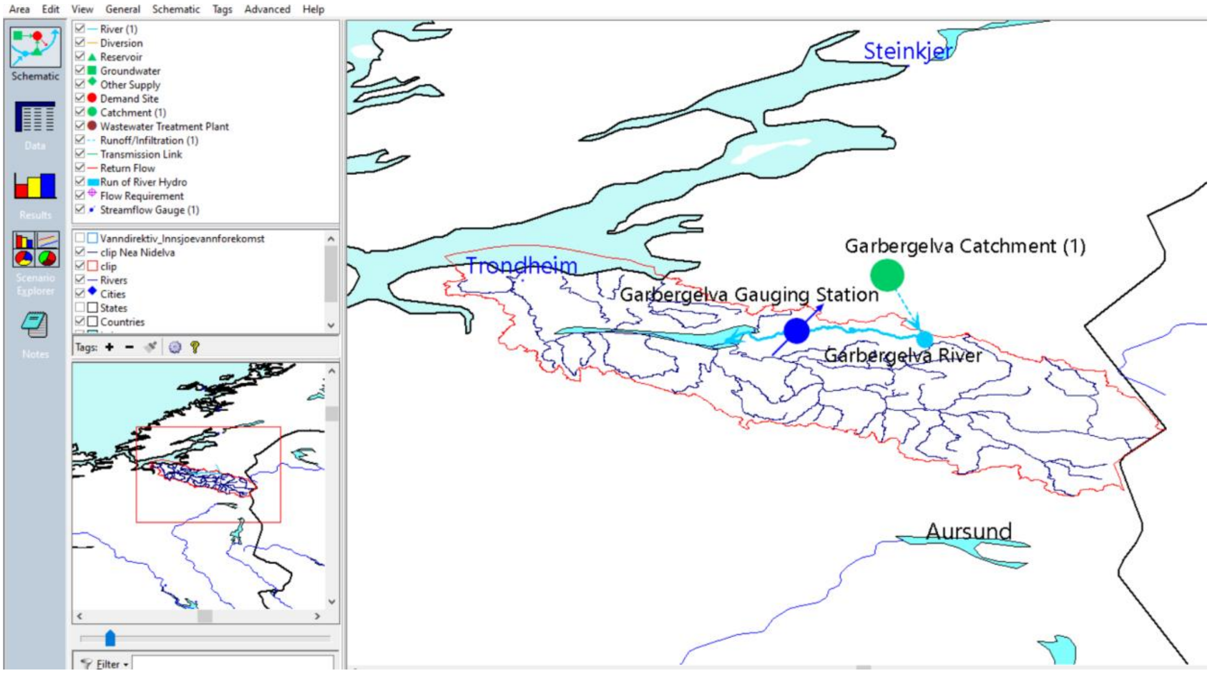


Figure 3-15 : Schematic view of Garbergelva catchment

3.4.1.2 Data addition

The elevation, land use and climate are the inputs of data in the catchment. This was done by going to the "Data View" and selecting the Garbergelva Catchment. Numerous fields were added manually to represent the data with respect to the elevation bands (200m elevation bands). The land-use types of the catchment were included under each of these bands (Figure 3-20).

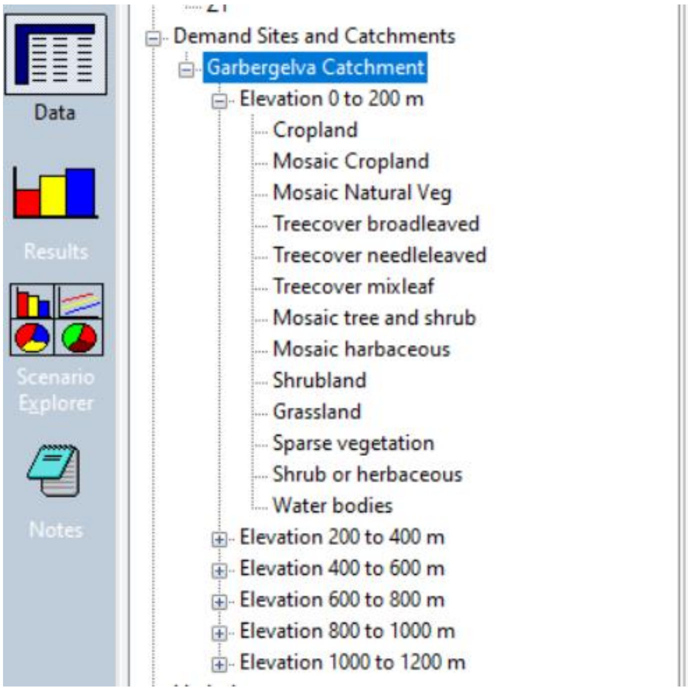
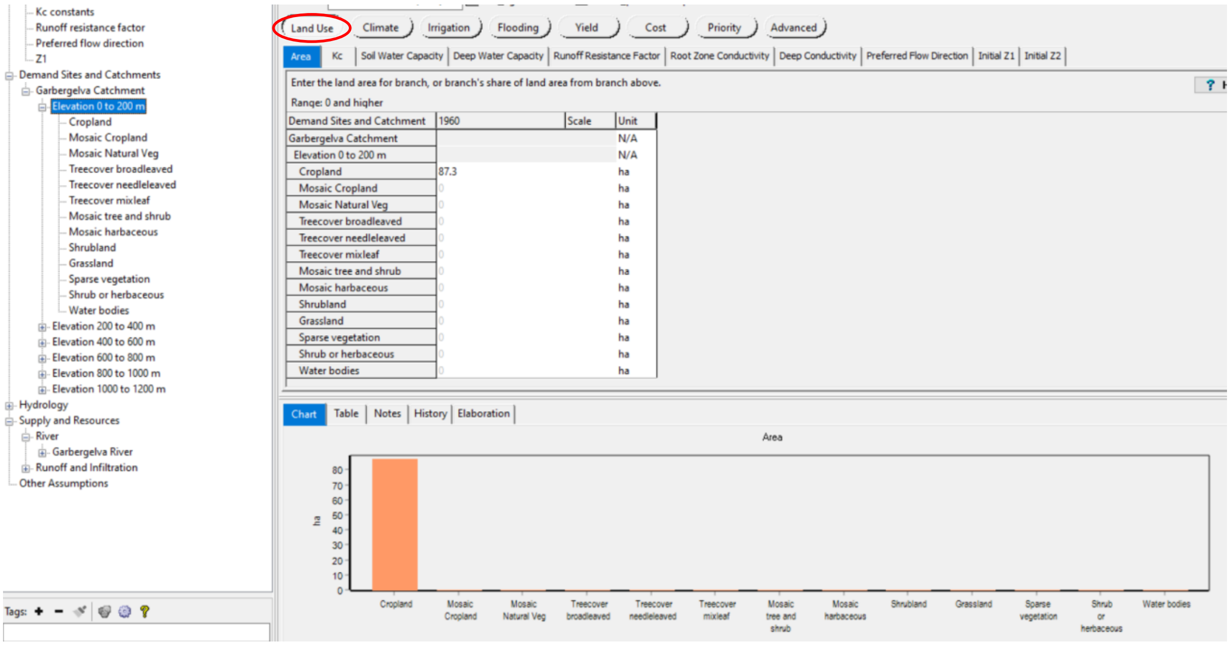


Figure 3-16 : Subfields under each elevation band of 200m

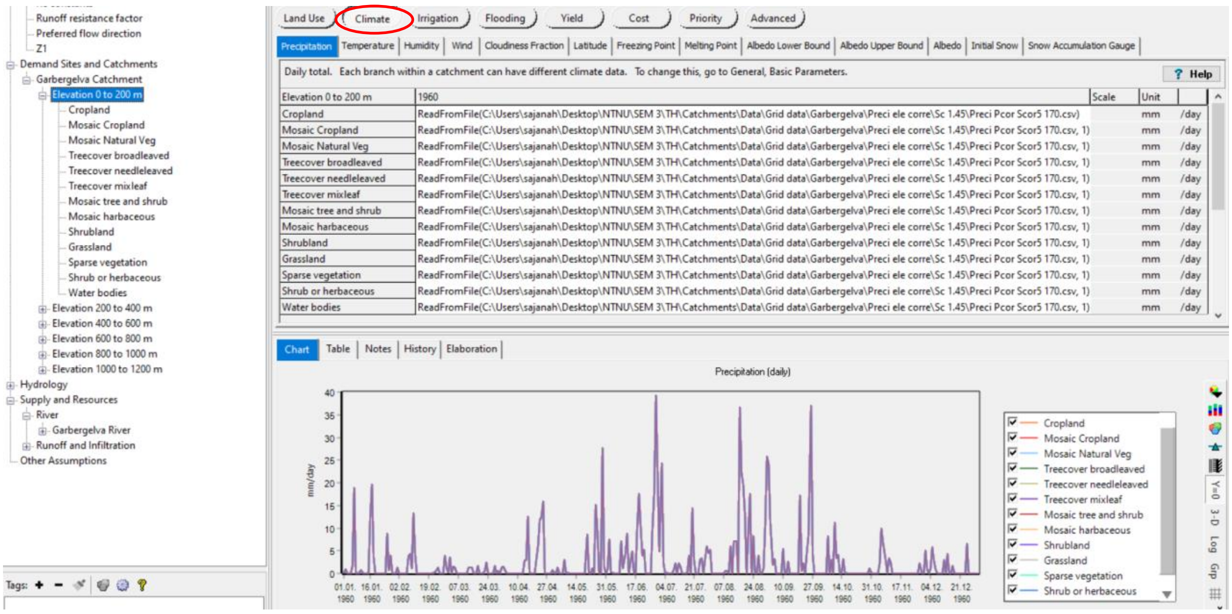
Land use and Climate data for each elevation band were added manually. The main purpose for adding various climate data for elevation bands is the variation of climate variables with the respect to elevation.



Enter the land area for branch, or branch's share of land area from branch above.

Range: 0 and higher

Demand Sites and Catchment	1960	Scale	Unit
Garbergelva Catchment			N/A
Elevation 0 to 200 m			N/A
Cropland	87.3		ha
Mosaic Cropland	0		ha
Mosaic Natural Veg	0		ha
Treecover broadleaved	0		ha
Treecover needleleaved	0		ha
Treecover mixleaf	0		ha
Mosaic tree and shrub	0		ha
Mosaic harbaceous	0		ha
Shrubland	0		ha
Grassland	0		ha
Sparse vegetation	0		ha
Shrub or herbaceous	0		ha
Water bodies	0		ha

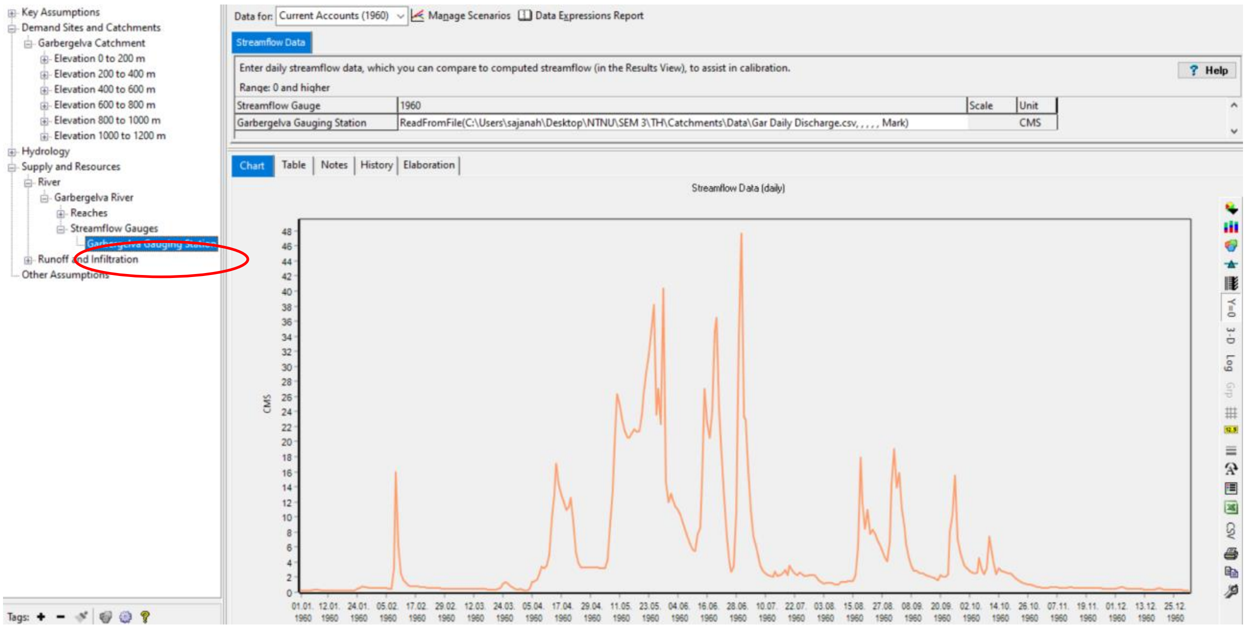


Daily total. Each branch within a catchment can have different climate data. To change this, go to General, Basic Parameters.

Elevation 0 to 200 m	1960	Scale	Unit	
Cropland	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv)		mm	/day
Mosaic Cropland	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Mosaic Natural Veg	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Treecover broadleaved	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Treecover needleleaved	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Treecover mixleaf	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Mosaic tree and shrub	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Mosaic harbaceous	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Shrubland	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Grassland	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Sparse vegetation	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Shrub or herbaceous	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day
Water bodies	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Grid data\Garbergelva\Preci ele corre\Sc 1.45\Preci Pcor Scor5 170.csv, 1)		mm	/day

Figure 3-17 : Land use and Climate data view in WEAP

The hydrological model should be verified with the comparison of the discharge data. Almost every data was added to the catchment up to this step. Since the hydrological model is required to be calibrated, the parameters should be varied to fit with the observed discharge of the Streamflow gauge. The flow data was added by selecting the Streamflow Gauge by the following path Supply and Resources – Garbergelva River – Streamflow Gauging Station as shown in the Figure 3-18.



Data for: Current Accounts (1960)

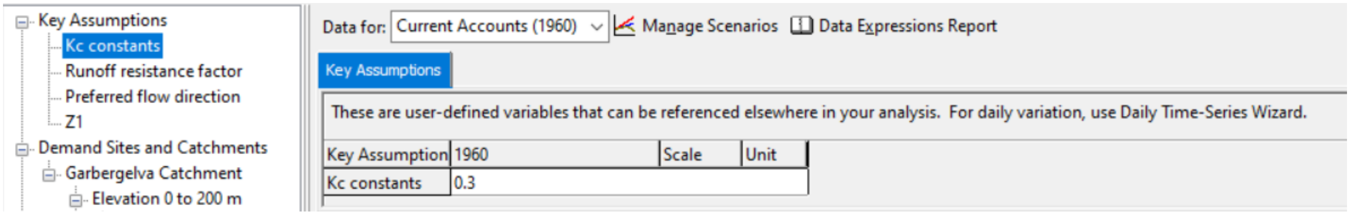
Enter daily streamflow data, which you can compare to computed streamflow (in the Results View), to assist in calibration.

Range: 0 and higher

Streamflow Gauge	1960	Scale	Unit
Garbergelva Gauging Station	ReadFromFile(C:\Users\sajanah\Desktop\NTNU\SEM 3\TH\Catchments\Data\Gar Daily Discharge.csv, , , , , Mark)		CMS

Figure 3-18: Flow data addition for the Streamflow gauge

It will be a complicated task to adjust the variables as many subclasses of land use under each elevation band in the model. Hence “Key Assumptions” should be added for the ease of adjusting the parameters for the entire catchment. This was included by adding a new field under the Key Assumptions Section available in the Data View (Figure 3-19). The field was edited in the name of the parameter. This should be linked with each land use subsection under the elevation band. It was done by dragging the added key assumption under the “Expression Builder” for each land use sub-category (Figure 3-20).

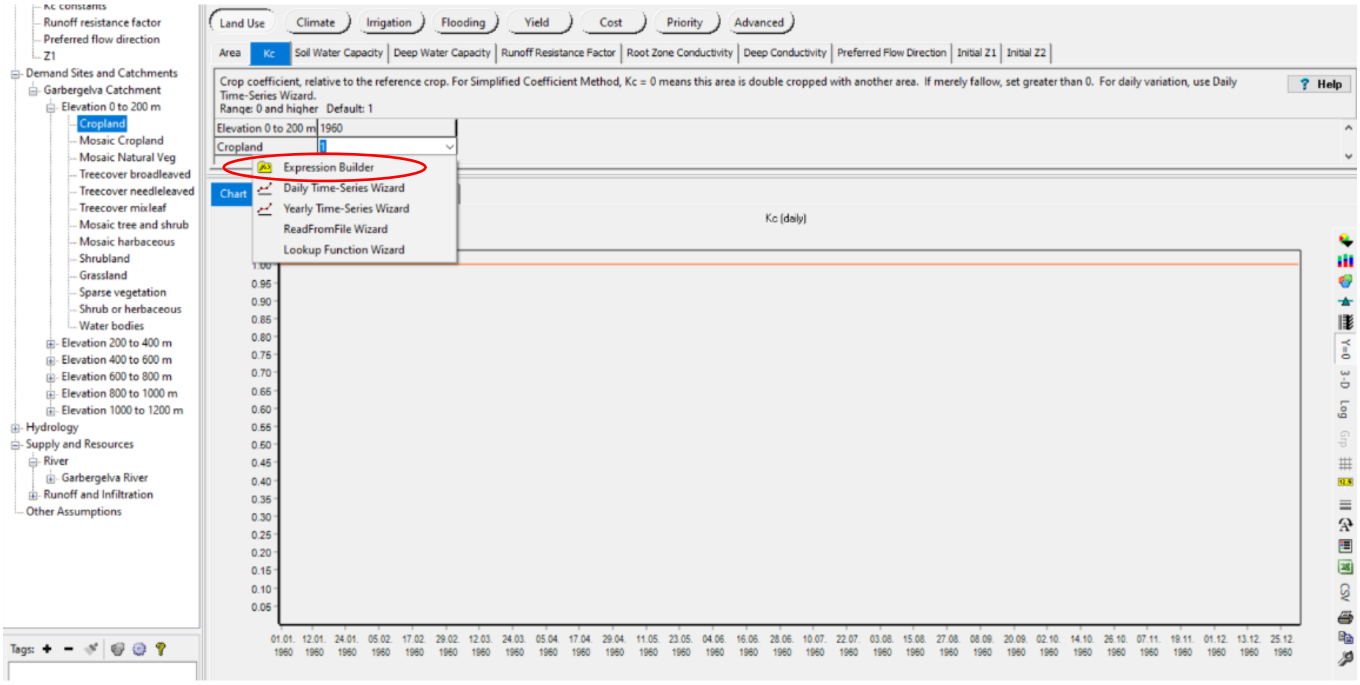


Data for: Current Accounts (1960)

These are user-defined variables that can be referenced elsewhere in your analysis. For daily variation, use Daily Time-Series Wizard.

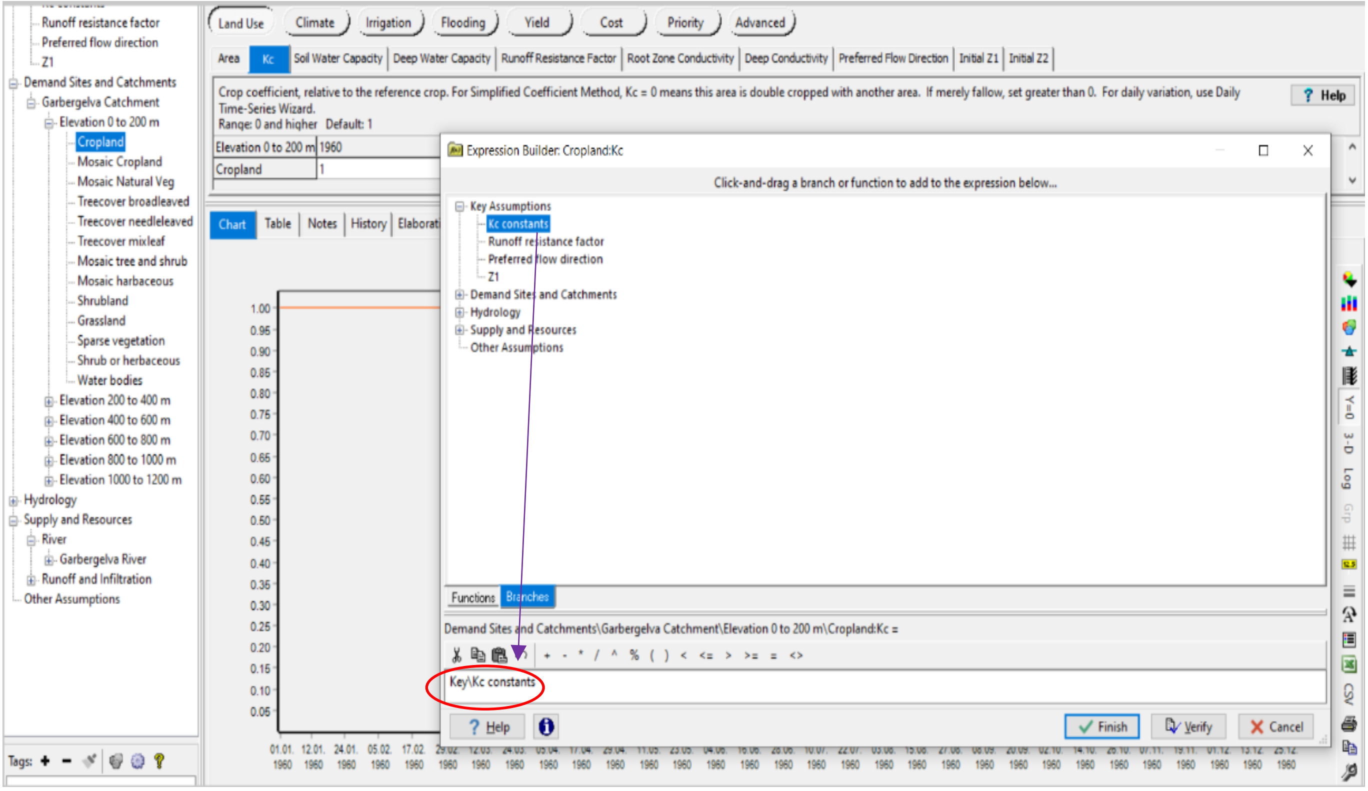
Key Assumption	1960	Scale	Unit
Kc constants	0.3		

Figure 3-19: Key Assumption for Crop coefficient Kc



Crop coefficient, relative to the reference crop. For Simplified Coefficient Method, Kc = 0 means this area is double cropped with another area. If merely fallow, set greater than 0. For daily variation, use Daily Time-Series Wizard.
Range: 0 and higher Default: 1

Elevation 0 to 200 m	1960
Cropland	1



Crop coefficient, relative to the reference crop. For Simplified Coefficient Method, Kc = 0 means this area is double cropped with another area. If merely fallow, set greater than 0. For daily variation, use Daily Time-Series Wizard.
Range: 0 and higher Default: 1

Elevation 0 to 200 m 1960
Cropland 1

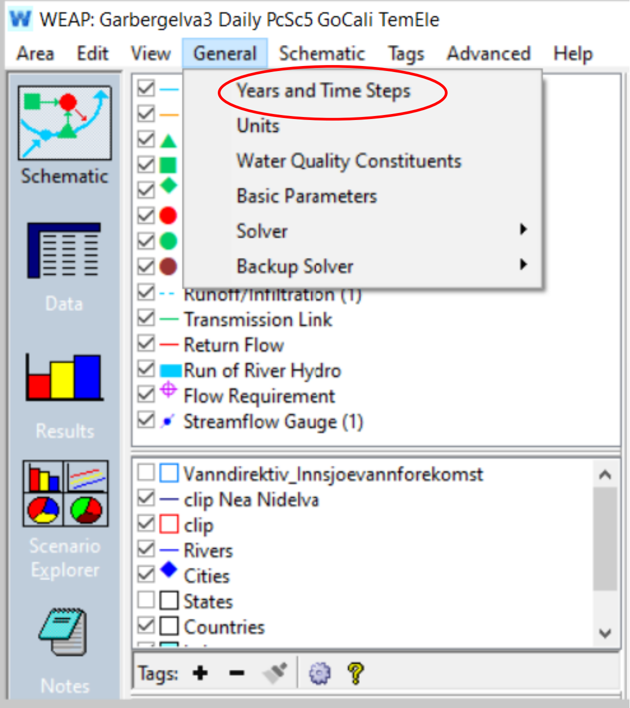
Demand Sites and Catchments\Garbergelva Catchment\Elevation 0 to 200 m\Cropland:Kc =

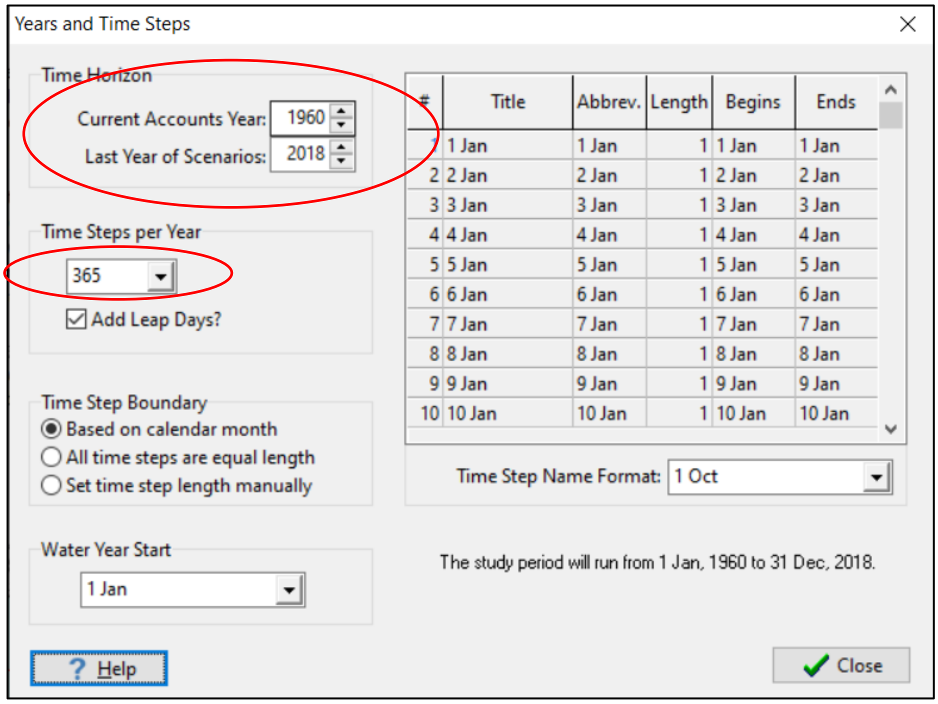
Key\Kc constants

Figure 3-20 : Linking Key Assumption for sub land use categories for elevation bands

3.4.1.3 General Settings prior to model run

The period in which the model should run was set under the General settings as in Figure 3-21 below.





Time Horizon

Current Accounts Year: 1960

Last Year of Scenarios: 2018

Time Steps per Year

365

☑ Add Leap Days?

Time Step Boundary

● Based on calendar month

○ All time steps are equal length

○ Set time step length manually

Water Year Start

1 Jan

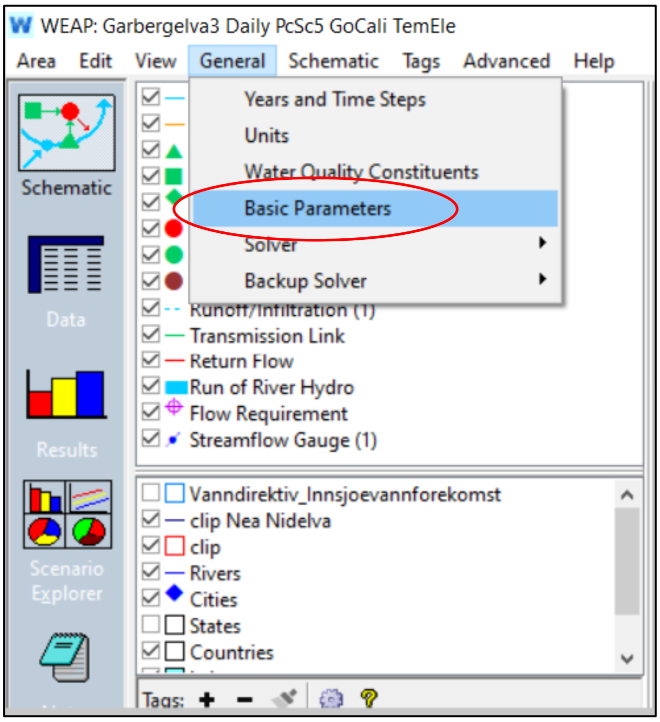
#	Title	Abbrev.	Length	Begins	Ends
1	1 Jan	1 Jan	1	1 Jan	1 Jan
2	2 Jan	2 Jan	1	2 Jan	2 Jan
3	3 Jan	3 Jan	1	3 Jan	3 Jan
4	4 Jan	4 Jan	1	4 Jan	4 Jan
5	5 Jan	5 Jan	1	5 Jan	5 Jan
6	6 Jan	6 Jan	1	6 Jan	6 Jan
7	7 Jan	7 Jan	1	7 Jan	7 Jan
8	8 Jan	8 Jan	1	8 Jan	8 Jan
9	9 Jan	9 Jan	1	9 Jan	9 Jan
10	10 Jan	10 Jan	1	10 Jan	10 Jan

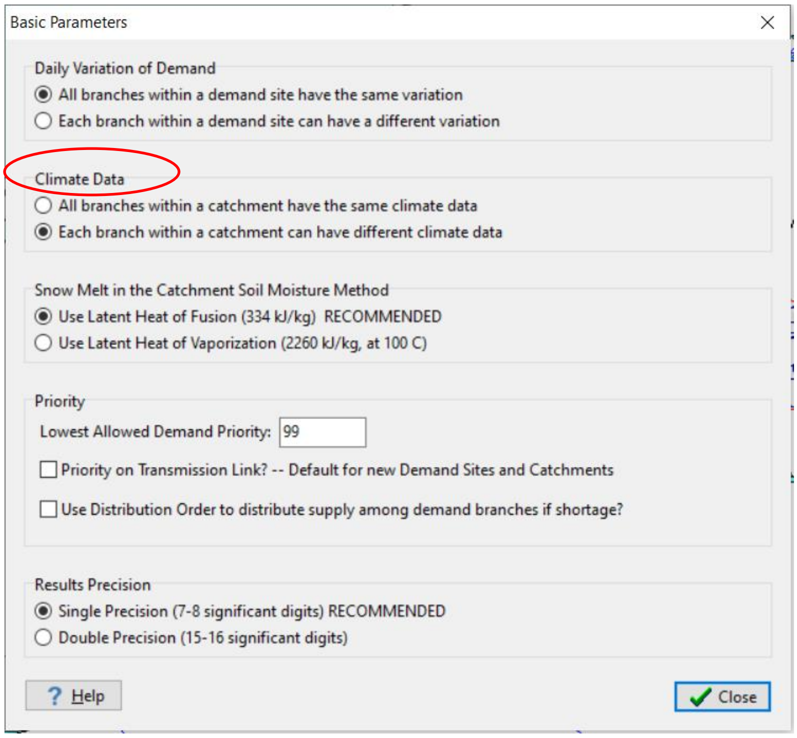
Time Step Name Format: 1 Oct

The study period will run from 1 Jan, 1960 to 31 Dec, 2018.

Figure 3-21: Setting of Years and Time Steps

The settings of climate data were adjusted before adding data as mentioned in section 3.4.1.2. It was set so it will have various climate data for each branch of the catchment (Figure 3-22).





Basic Parameters

Daily Variation of Demand

● All branches within a demand site have the same variation

○ Each branch within a demand site can have a different variation

Climate Data

○ All branches within a catchment have the same climate data

● Each branch within a catchment can have different climate data

Snow Melt in the Catchment Soil Moisture Method

● Use Latent Heat of Fusion (334 kJ/kg) RECOMMENDED

○ Use Latent Heat of Vaporization (2260 kJ/kg, at 100 C)

Priority

Lowest Allowed Demand Priority: 99

☐ Priority on Transmission Link? -- Default for new Demand Sites and Catchments

☐ Use Distribution Order to distribute supply among demand branches if shortage?

Results Precision

● Single Precision (7-8 significant digits) RECOMMENDED

○ Double Precision (15-16 significant digits)

Figure 3-22: Adjustment of Climate data setting in WEAP

3.4.2 Stokke

The same methodology was followed for model at Stokke station as per Garbergelva model. The catchment characteris, elevation and land use, climate data was included to the WEAP model. The flow data of Stokke gauging station was added under the Streamflow gauge.

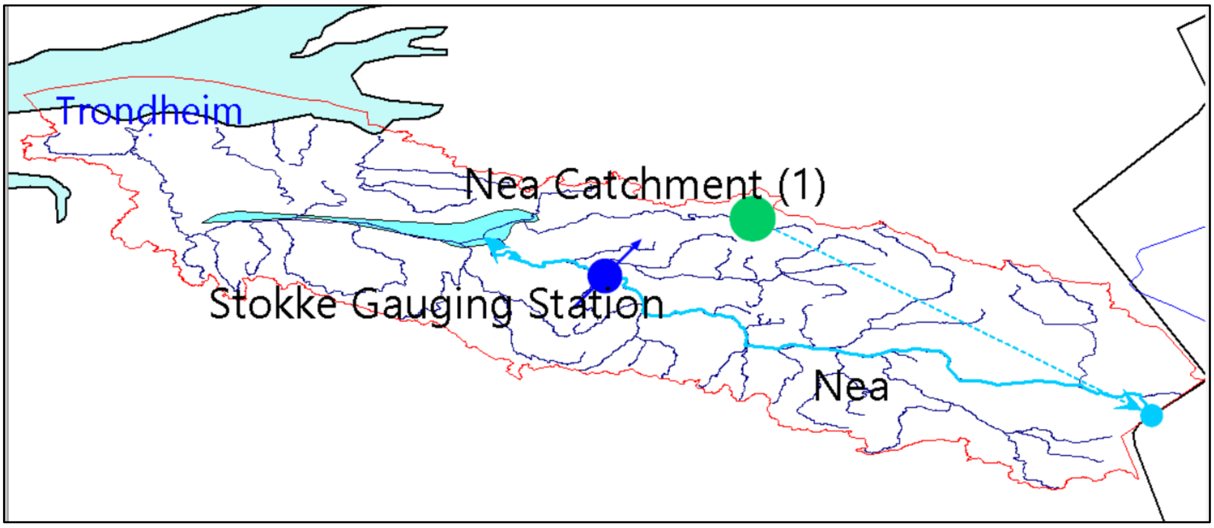


Figure 3-23: Schematic view of Stokke model

3.4.3 Kulset Bru

The calibrated Stokke model was saved into a new version and edited with elevation and landuse data related to the catchment representing the outlet Kulset Bru. The flow data regarding the discharge of Kulset was included under streamflow data.

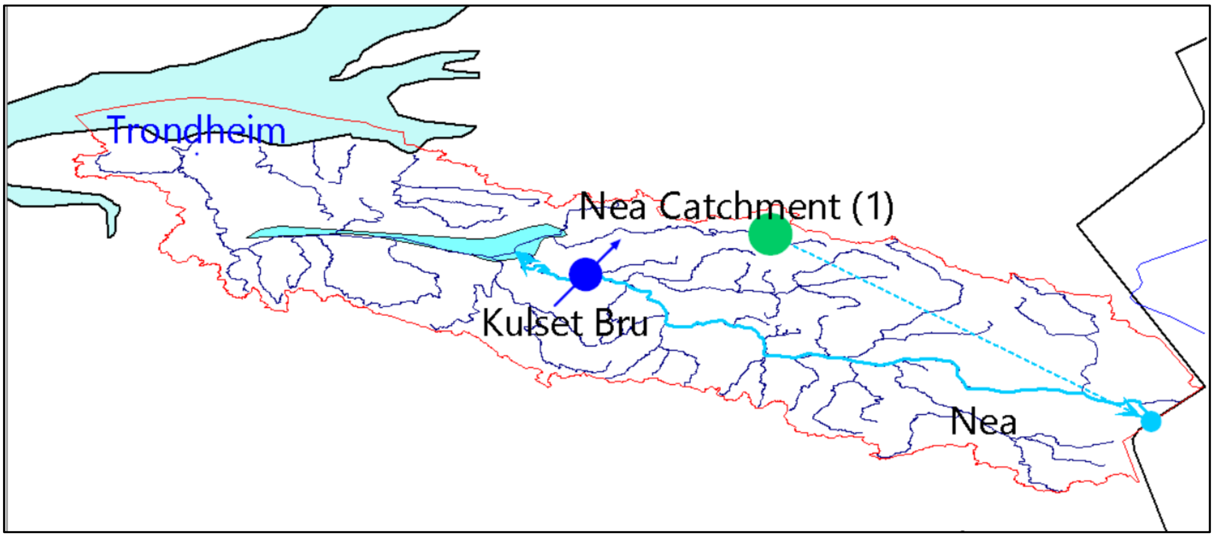
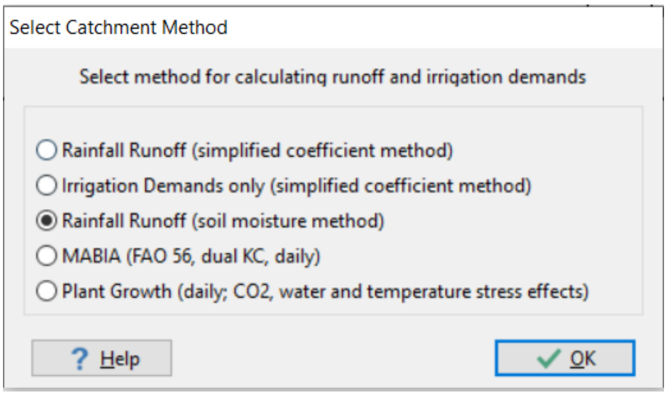


Figure 3-24: Schematic view of Kulset model

3.5 Soil Moisture Method

Simulation of runoff can be generated by one of the following methods in was mentioned by the Figure 3-25. The input data required to be entered and generation of runoff will be varied with regard to the selection method. Rainfall-Runoff (soil moisture) method was selected.


Select Catchment Method

Select method for calculating runoff and irrigation demands

○ Rainfall Runoff (simplified coefficient method)
○ Irrigation Demands only (simplified coefficient method)
● Rainfall Runoff (soil moisture method)
○ MABIA (FAO 56, dual KC, daily)
○ Plant Growth (daily; CO2, water and temperature stress effects)

Figure 3-25: Methods for calculation of runoff and irrigation depands in WEAP

3.5.1 Concept

The Soil Moisture Method divides the catchment into two buckets or layers.

1. Root Zone
2. Deep Zone

The water balance in these two layers occurs in different processes. The catchment has a subclassification which is defined by disaggregation in order to represent the hydrological process such as runoff, evapotranspiration, percolation and infiltration. Each categorization of the catchment relates to the root zone whilst deep zone is allocated to the entire catchment. The process of water balance in this method is affected by nine parameters.

1. Crop coefficient (Kc)
2. Soil water capacity (Sw)
3. Deep water capacity (Dw)
4. Runoff resistance factor (RRF)
5. Root zone conductivity (Ks)
6. Deep conductivity (Kd)
7. Preferred flow direction (f)
8. Initial Z1 (Z1)
9. Initial Z2 (Z2)

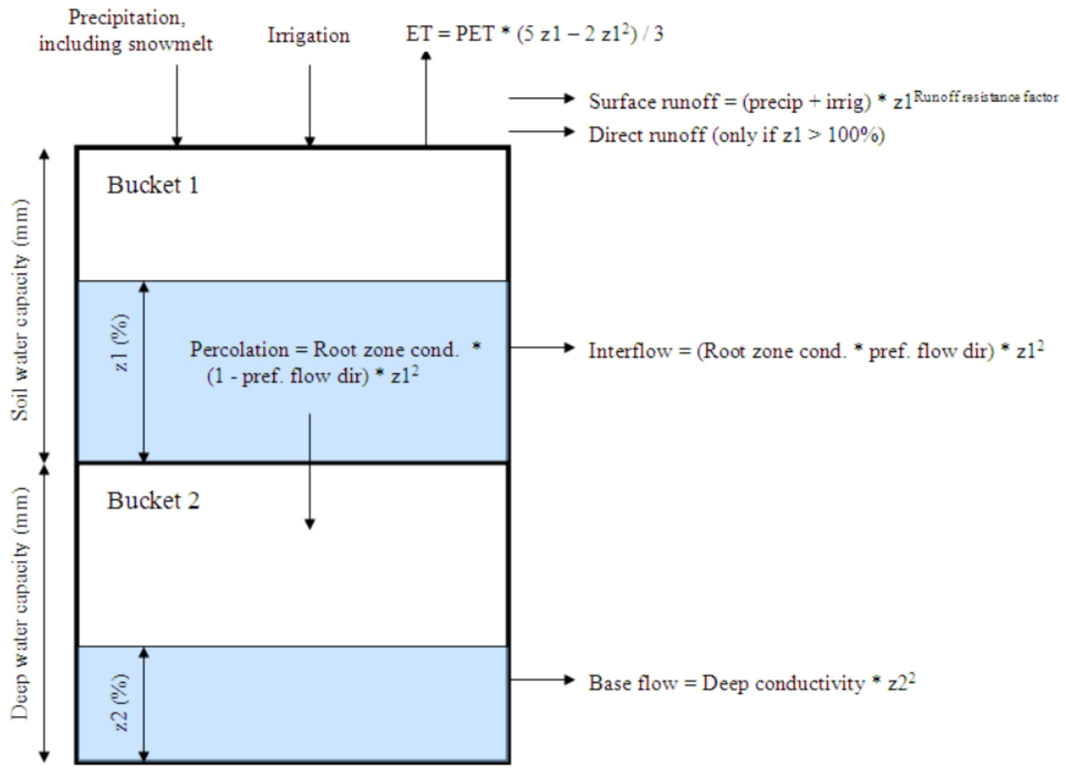


Figure 3-26: The two-bucket conceptual diagram (Sieber & Purkey, 2015)

The conceptual two bucket diagram which explains the hydrological processes and catchment response is shown in the Figure 3-26. The soil moisture method transforms the climate data of the catchment into the flow through the rivers in the form of runoff, interflow, percolation or baseflow. The surface runoff is manipulated by the runoff resistance factor other than the remaining precipitation and irrigation that doesn't move to the root zone. Once the root zone is fully saturated, the catchment generates direct runoff. Interflow and percolation are the outflows from the root zone that depends on soil water capacity, root zone conductivity and preferred flow direction. The preferred flow direction is the decisive factor that separates the percolation from the interflow. The baseflow in the deep zone controls by the deep water capacity and deep conductivity.

Similar to most of the hydrological models, it is necessary to set the initial conditions for certain parameters under the soil moisture method. The relative storages of the root zone (Initial Z1) and deep zone (Initial Z2) are represented as a percentage of the total water capacity of the root zone and deep zone respectively.

The key equations of the mathematical model in soil moisture method (Sieber & Purkey, 2015) are mentioned below.

- For root zone,

$$S_{w_j}\frac{dz_{i,j}}{dt} = P_e(t) - PET(t)k_{c,j}(t)\left(\frac{5z_{1,j} - 2{z^2}_{1,j}}{3}\right) - P_e(t){z_{1,j}}^{\frac{RRF_i}{2}} - f_j k_s {z^2}_{1,j} - (1 - f_j)k_s {z^2}_{1,j}$$

$$S_{w_j}\frac{dz_{i,j}}{dt} = Top\ bucket\ soil\ moisture$$

$$P_e(t) = Effective\ precipitation$$

$$PET(t)k_{c,j}(t)\left(\frac{5z_{1,j} - 2{z^2}_{1,j}}{3}\right) = Evaportranspiration$$

$$P_e(t){z_{1,j}}^{\frac{RRF_i}{2}} = Surface\ runoff$$

$$f_j k_s {z^2}_{1,j} = Interflow$$

$$(1 - f_j)k_s {z^2}_{1,j} = Percolation$$

- For deep zone,

$$Dw_j\frac{dz_{2,j}}{dt} = (1 - f)k_s {z^2}_{1,j} - k_d {z^2}_{2,j}$$

$$Dw_j\frac{dz_{2,j}}{dt} = Deep\ bucket\ soil\ moisture$$

$$(1 - f)k_s {z^2}_{1,j} = Percolation$$

$$k_d {z^2}_{2,j} = Baseflow$$

The data required to enter depends on the method which is selected (Sieber & Purkey, 2015). In this method, manly land and climate variables must be entered. The catchment area and the other nine parameters mentioned in the second paragraph of this section are required to add under land variables. The climate variables necessary for the model are represented in the following Figure 3-27.

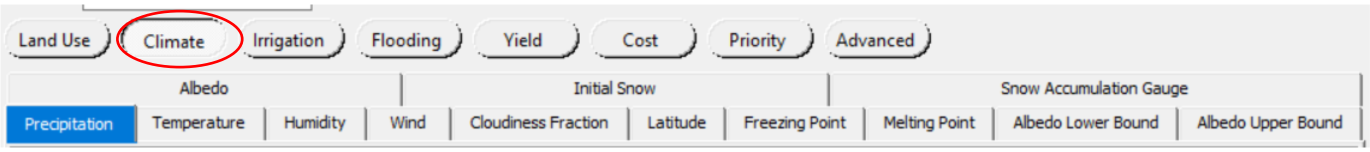
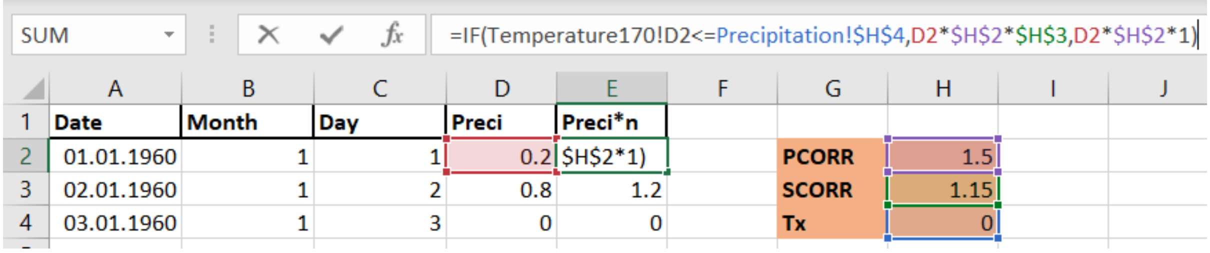


Figure 3-27: Climate variable under soil moisture method

3.5.2 Climate data processing

As it is explained under the section 3.2.1, the precipitation and temperature data were gathered from Senorge.no as gridded data. The precipitation data was collected at the center of the catchment for Garbergelva, Stokke and Kulset bru. Precipitation (PCORR) and snow correction (SCORR) was considered before inputting the gridded data for the WEAP model. Since the snow correction depends on the temperature and temperature at a variety of elevation bands was gathered, the precipitation at an array of elevation bands was processed. A section of the generated excel sheet for precipitation is shown below.



=IF(Temperature170!D2<=Precipitation!H4,D2*H2*H3,D2*H2*1)

	A	B	C	D	E	F	G	H	I	J
1	Date	Month	Day	Preci	Preci*n					
2	01.01.1960	1	1	0.2	H2*1)		PCORR	1.5		
3	02.01.1960	1	2	0.8	1.2		SCORR	1.15		
4	03.01.1960	1	3	0	0		Tx	0		

Figure 3-28: Generated excel sheet for precipitation with PCORR and SCORR

3.6 Calibration of the hydrological model

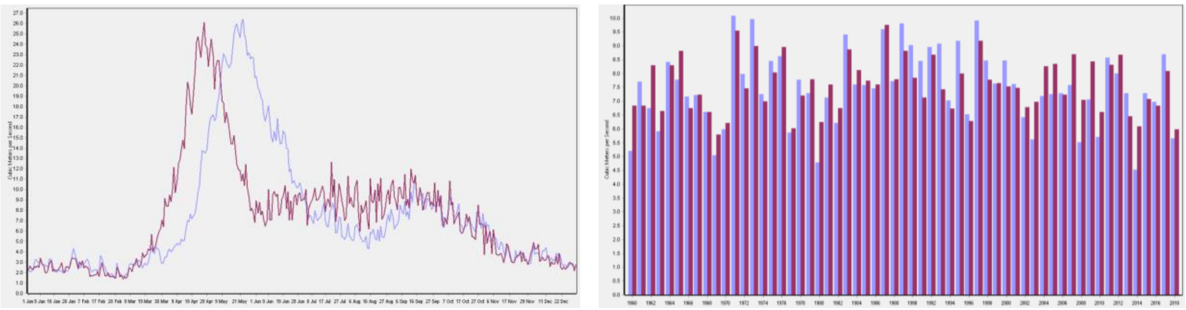
Every hydrological model must be calibrated with the observed data. Softwares used for past studies of flood dampening were also calibrated before the analysis (section 2.3). In the thesis, firstly Garbergelva model was run by the XA solver and compared the goodness of fit for streamflow results with the observed gauge data. Evaporation and Snow depth was also checked with the observed data to have a practically ideal hydrological model that could define the almost the actual situation of the catchment. The calibrated climate parameters in the Garbergelva model were transformed to the Stokke model located in the adjacent Nea basin. The calibration process of each model is explained in the following subsections.

3.6.1 Manual calibration

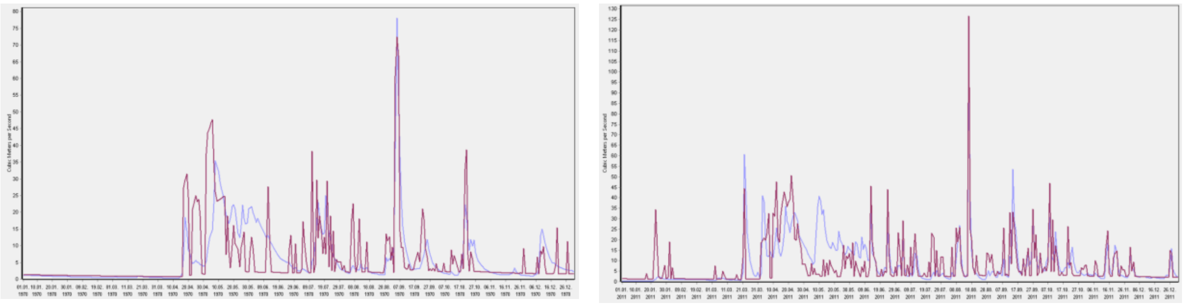
This calibration was done manually by varying the climate and land variables mentioned in section 3.5.1. It took long period of time to understand the behaviour of streamflow with respect to the parameters. On the other hand, it is the best way to understand what is happening inside the conceptual two bucket system which is the best way to assess the suitability of WEAP when calibrating in Norwegian climate conditions.

3.6.1.1 Garbergelva

The model was run and compared the streamflow results with the observed discharge. The Land variables were changed manually considering their effects on each layer as it is explained in section 3.5.1. The climate variables had a considerable effect on the seasonality variation of the streamflow. The melting point and freezing point paid a pivotal role in this subject. This was simultaneously varied with the precipitation correction (PCORR) and snow correction (SCORR) for the gridded precipitation data.



Daily average Annual totals



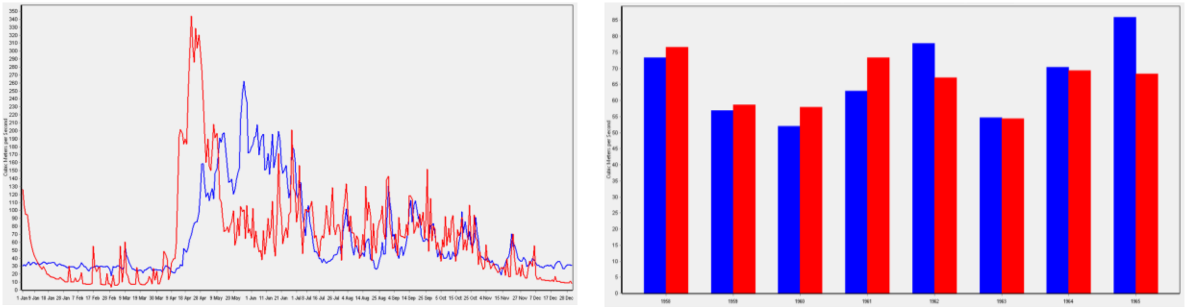
Specific years

1970 2011

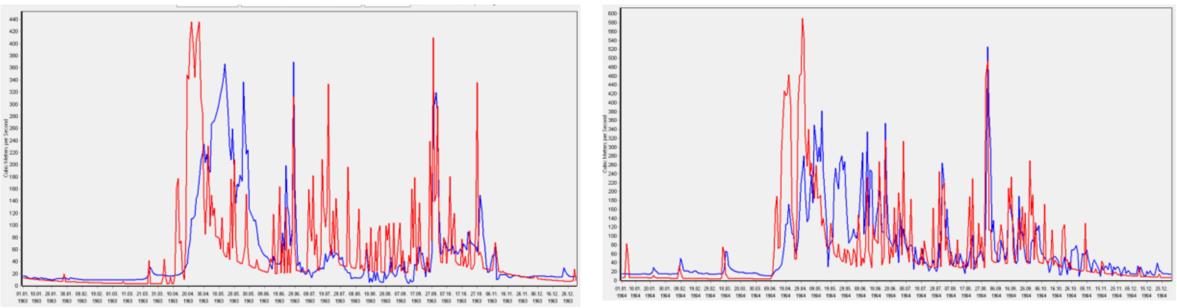
Figure 3-29: The results obtained during simulation of Garbergelva WEAP model

3.6.1.2 Stokke

The calibrated climate parameters (melting point and freezing point) were directly transferred from the Garbergelva model to this model setup. The land parameters and the PCORR & SCORR were changed to get the perfect goodness of fit for streamflow. The model was run for 1958-1965 taking into account having fewer regulations in the Nea basin. This is further explained in the section 5.2.2. The daily average, annual total and specific years were analyzed while calibrating the model in order to visualize the seasonal, and annual variation of the streamflow. PBIAS (percentage bias) was one of the main parameters that was checked to achieve the goodness of fit.



Daily average Annual totals



Specific years

1963 1964

Figure 3-30: The results obtained during simulation of Stokke model

3.6.2 Automatic Calibration (PEST calibration)

The **P**arameter **EST**imation tool (PEST) in WEAP permits the model user to compare the WEAP outputs to based on model parameters and modifying them to improve its accuracy. It is possible to use PEST to calibrate the WEAP model with one or more parameters that will be helpful in specifically soil moisture method. WEAP will run PEST once for each scenario selected. In a single PEST run, PEST will repeatedly cycle through modifying WEAP data variables, running WEAP calculations, then examining the results. After PEST has run for each specific scenario, WEAP will move to the Scenario Explorer View, showing each parameter to calibrate in the Data Section, and each Observation to calibrate to in the Results Section, for the chosen scenarios (Sieber & Purkey, 2015). In this thesis, also used PEST to calibrate the model by setting up 9 land use parameters mentioned in section 3.5.1. It took more than one hour and thirty minutes to finish the iterations. The final output obtained is shown in **Figure 3-31**.

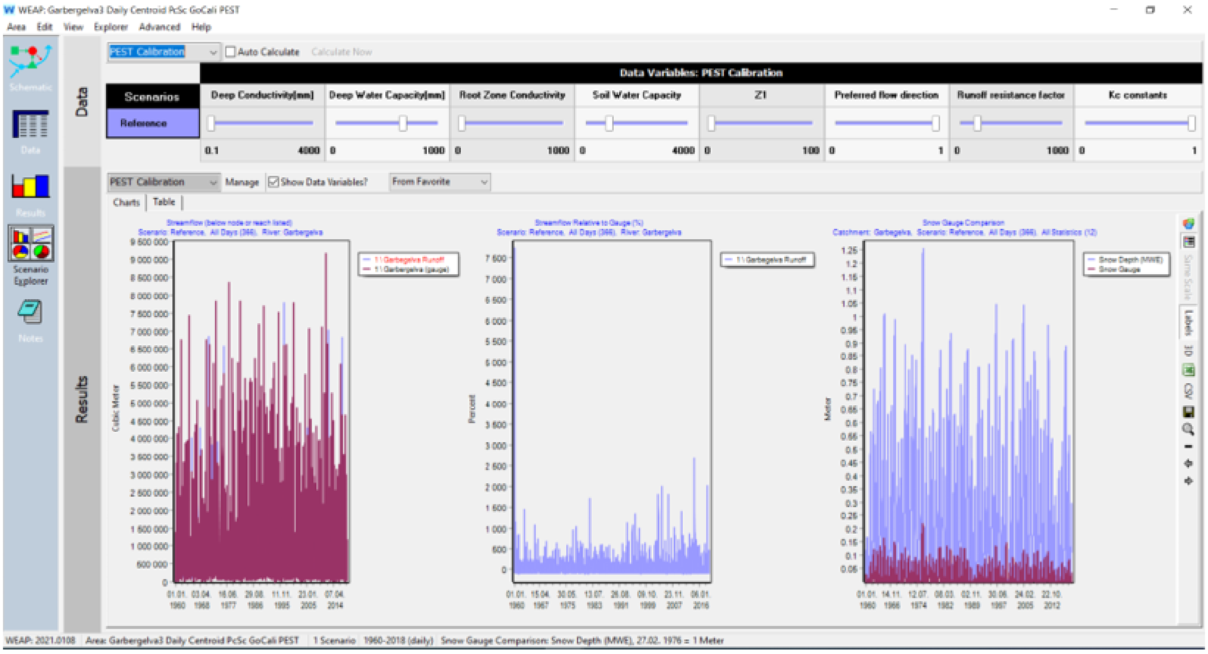


Figure 3-31: The results of PEST calibration

Since many parameters were set for calibration of the model, the obtained results were not good. On the other hand, the timeseries were set to be from 1960-2018 which will also take a long time. The performance of the computer also might have affected the timing on performing iterations. In my concern, this method is quite harder to understand the effect of parameters on the model outputs. It would be best to limit the number of varying parameters to achieve the results in shorter period of time.

4 Results

The primary aim of this section is to exemplify the results obtained from the WEAP models which were run for the catchments Garbergelva, Stokke and Kulset Bru. The model outputs obtained by running the WEAP model and varying the parameters for the three river basins are as described in the sections 3.4 and 3.6.1.

4.1 Garbergelva

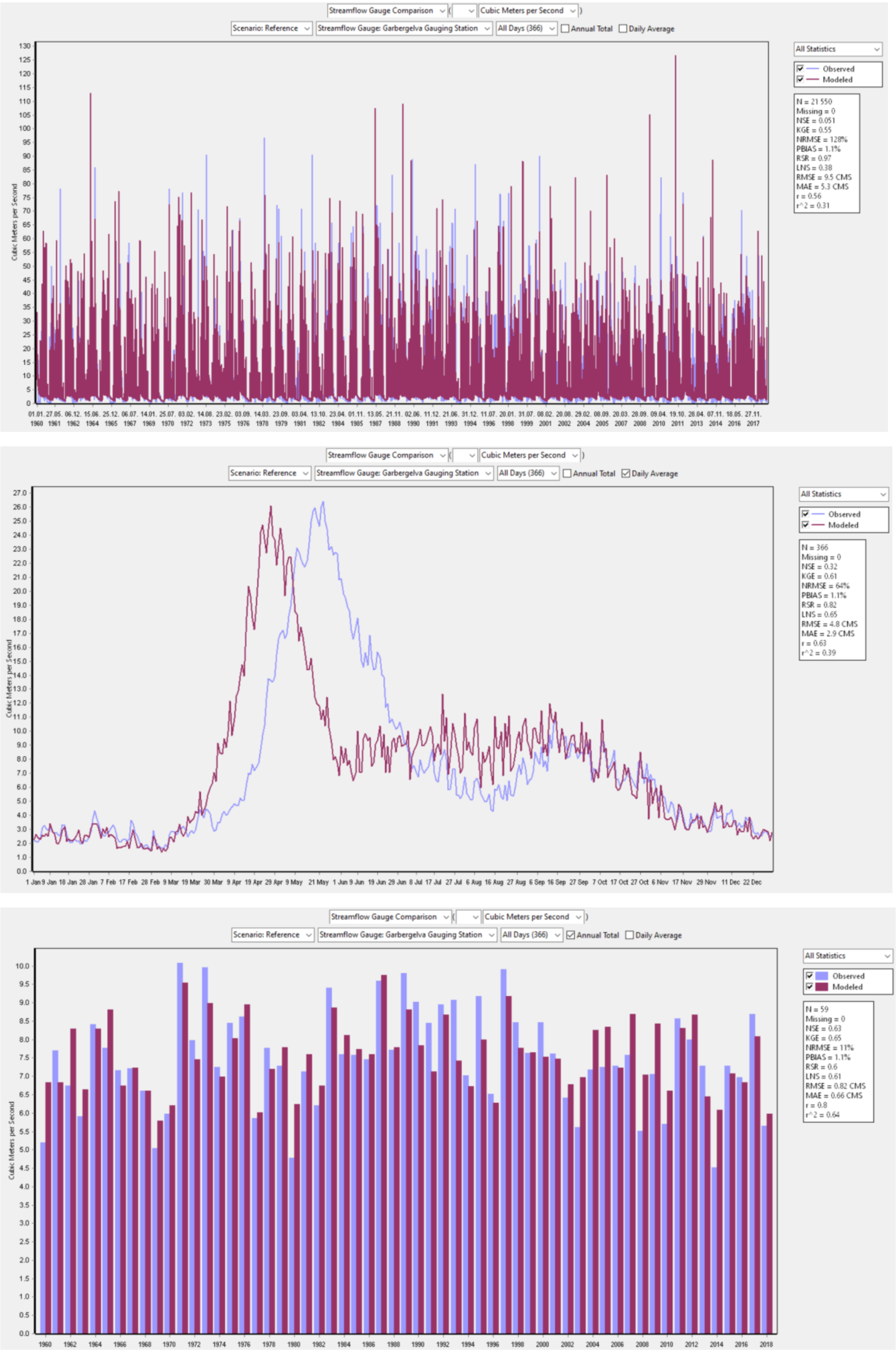
Garbergelva model was run for the period of 1960-2018 and analysed the results. The streamflow, snow depth and evaporation of the model was analysed separately.

4.1.1 Streamflow

The Land and climate parameters of the model was varied to achieve the perfect goodness of fit. The best calibrated at the Melting point 0.5°C and freezing point at 0°C. The PCORR and SCORR were set to 1.5 and 1.15. The other calibration parameters are as mentioned below.

Table 4-1: Calibrated parameters for Garbergelva model

Parameter	Value	Unit
Melting Point	0.5	Celsius
Freezing Point	0	Celsius
Crop coefficient (Kc)	0.3	
Soil water capacity (Sw)	1000	mm
Deep water capacity (Dw)	1000	mm
Runoff resistance factor (RRF)	0.1	
Root zone conductivity (Ks)	2000	mm/day
Deep conductivity (Kd)	20	mm/day
Preferred flow direction (f)	0.15	
Initial Z1 (Z1)	30	Percentage (%)
Initial Z2 (Z2)	30	Percentage (%)



Streamflow Gauge Comparison (Cubic Meters per Second)

Scenario: Reference | Streamflow Gauge: Garbergelva Gauging Station | All Days (366) | ☐ Annual Total | ☐ Daily Average

All Statistics

☑ Observed
☑ Modeled

N = 21 550
Missing = 0
NSE = 0.051
KGE = 0.55
NRMSE = 128%
PBIAS = 1.1%
RSR = 0.97
LNS = 0.38
RMSE = 9.5 CMS
MAE = 5.3 CMS
r = 0.56
r^2 = 0.31

Streamflow Gauge Comparison (Cubic Meters per Second)

Scenario: Reference | Streamflow Gauge: Garbergelva Gauging Station | All Days (366) | ☐ Annual Total | ☑ Daily Average

All Statistics

☑ Observed
☑ Modeled

N = 366
Missing = 0
NSE = 0.32
KGE = 0.61
NRMSE = 64%
PBIAS = 1.1%
RSR = 0.82
LNS = 0.65
RMSE = 4.8 CMS
MAE = 2.9 CMS
r = 0.63
r^2 = 0.39

Streamflow Gauge Comparison (Cubic Meters per Second)

Scenario: Reference | Streamflow Gauge: Garbergelva Gauging Station | All Days (366) | ☑ Annual Total | ☐ Daily Average

All Statistics

☑ Observed
☑ Modeled

N = 59
Missing = 0
NSE = 0.63
KGE = 0.65
NRMSE = 11%
PBIAS = 1.1%
RSR = 0.6
LNS = 0.61
RMSE = 0.82 CMS
MAE = 0.66 CMS
r = 0.8
r^2 = 0.64

Figure 4-1: Comparison of the streamflow for daily step (upper), daily average (middle) and annual totals (lower) variation with observed discharge

The streamflow variation at the Garbergelva gauge is illustrated for the daily results, daily average and the annual total for the calibration period. The PBIAS is kept as low as 1.1%. On the negative note, there is a slight delay in achieving the peak flow although the magnitude is almost the same when considering the daily average variation of the streamflow (Figure 4-1). This is directly dependent on the climate variables used in calibrating the model. The melting point and freezing point affect on the timing of the flood peak. A separate analysis was done in section 5.1.1, to show the effect of these two climate variables on the streamflow.

4.1.2 Evaporation

The evaporation results for Garbergelva model is illustrated below.

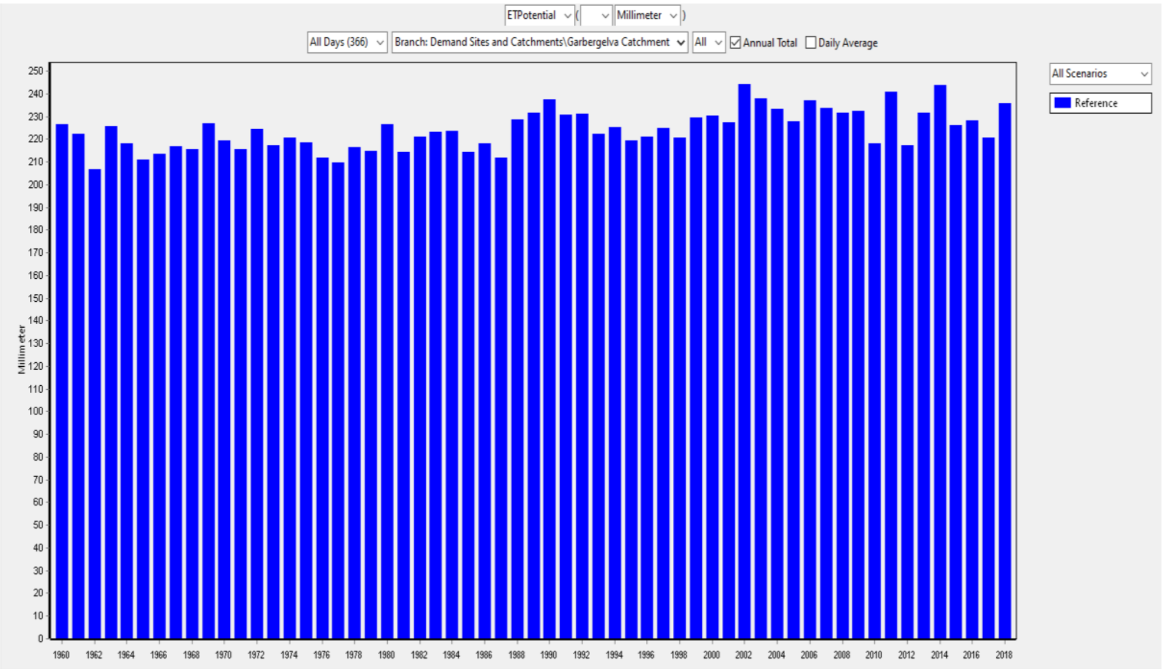
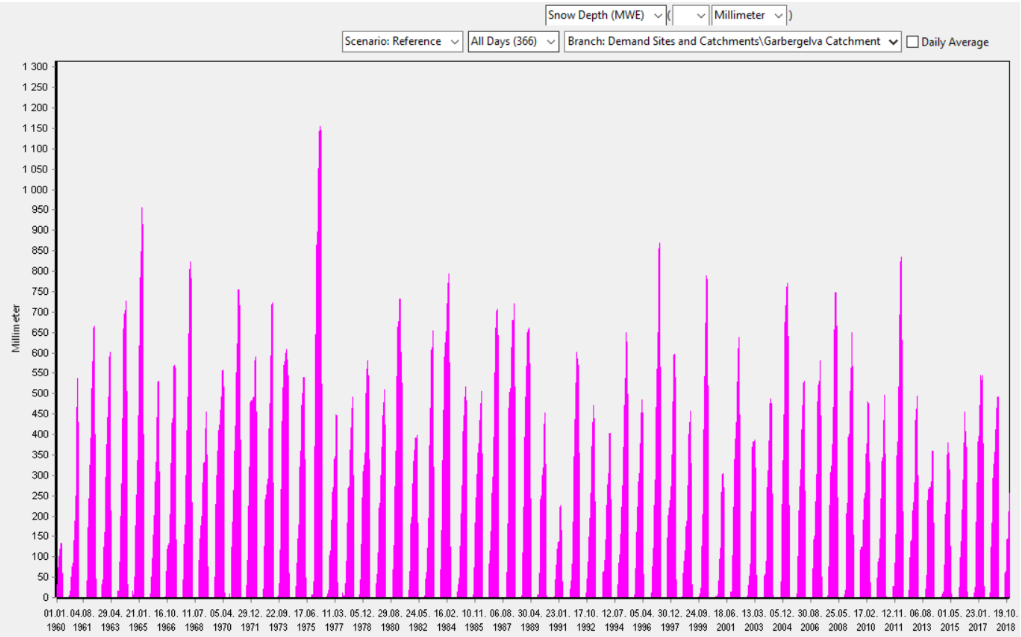


Figure 4-2: Annual totals of evaporation for Garbergelva catchment

4.1.3 Snow depth

The Snow depth results for Garbergelva model is illustrated below. It is represented with respect to the elevation band of 600-800m for the entire period.


Snow Depth (MWE) Millimeter

Scenario: Reference All Days (366) Branch: Demand Sites and Catchments\Garbergelva Catchment ☐ Daily Average

Figure 4-3: Snow depth for Garbergelva catchment

4.2 Stokke

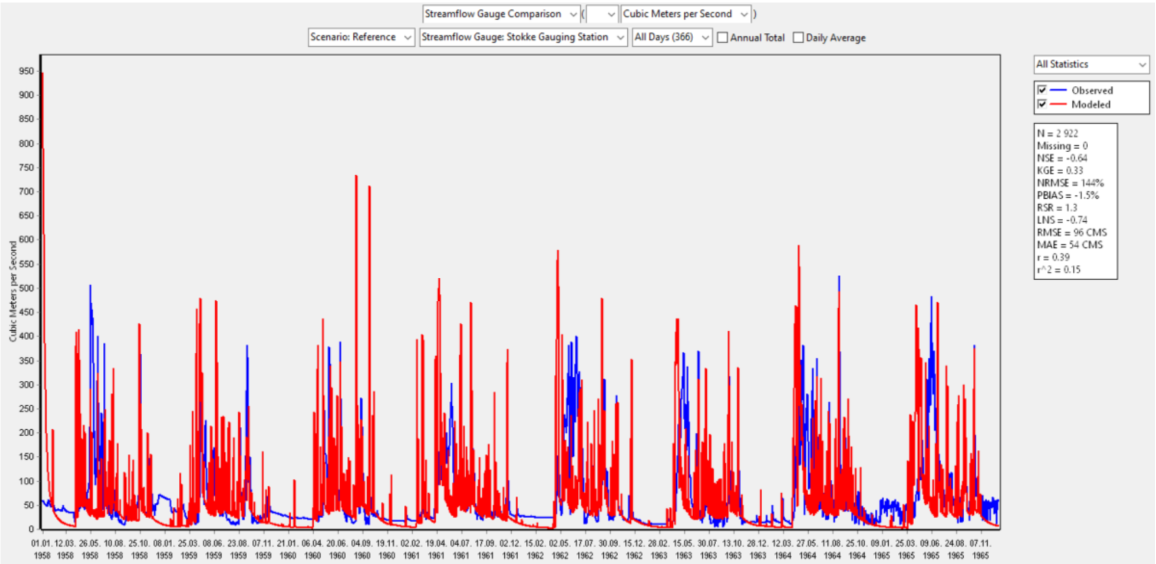
Stokke model was run for the period of 1958-1965 and analysed the results. The streamflow, snow depth and evaporation of the model was analysed separately.

4.2.1 Streamflow

The Land of the model and PCORR and SCORR of the gridded precipitation data was varied to achieve the perfect goodness of fit. The best calibrated Melting point and freezing point of Garbergelva model was directly transferred to the Stokke model. The PCORR and SCORR were set to 1.15. The other calibration parameters are as mentioned below.

Table 4-2: Calibrated parameters for Stokke model

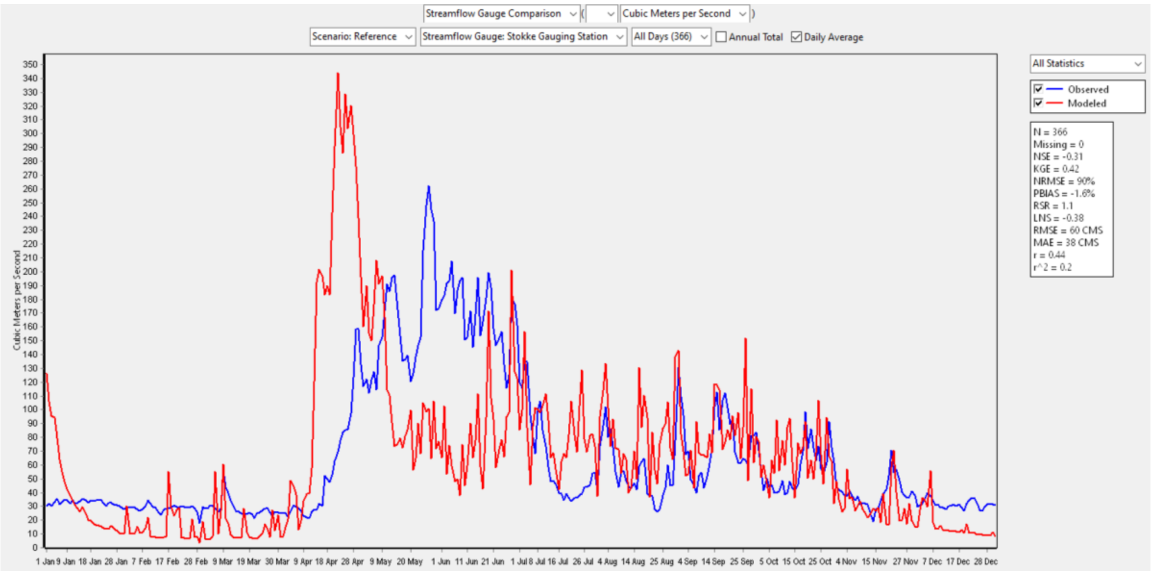
Parameter	Value	Unit
Melting Point	0.5	Celsius
Freezing Point	0	Celsius
Crop coefficient (Kc)	0.2	
Soil water capacity (Sw)	1000	mm
Deep water capacity (Dw)	1000	mm
Runoff resistance factor (RRF)	0.125	
Root zone conductivity (Ks)	4000	mm/day
Deep conductivity (Kd)	20	mm/day
Preferred flow direction (f)	0.15	
Initial Z1 (Z1)	30	Percentage (%)
Initial Z2 (Z2)	30	Percentage (%)



Streamflow Gauge Comparison ( ) Cubic Meters per Second

Scenario: Reference | Streamflow Gauge: Stokke Gauging Station | All Days (366) | ☐ Annual Total | ☐ Daily Average

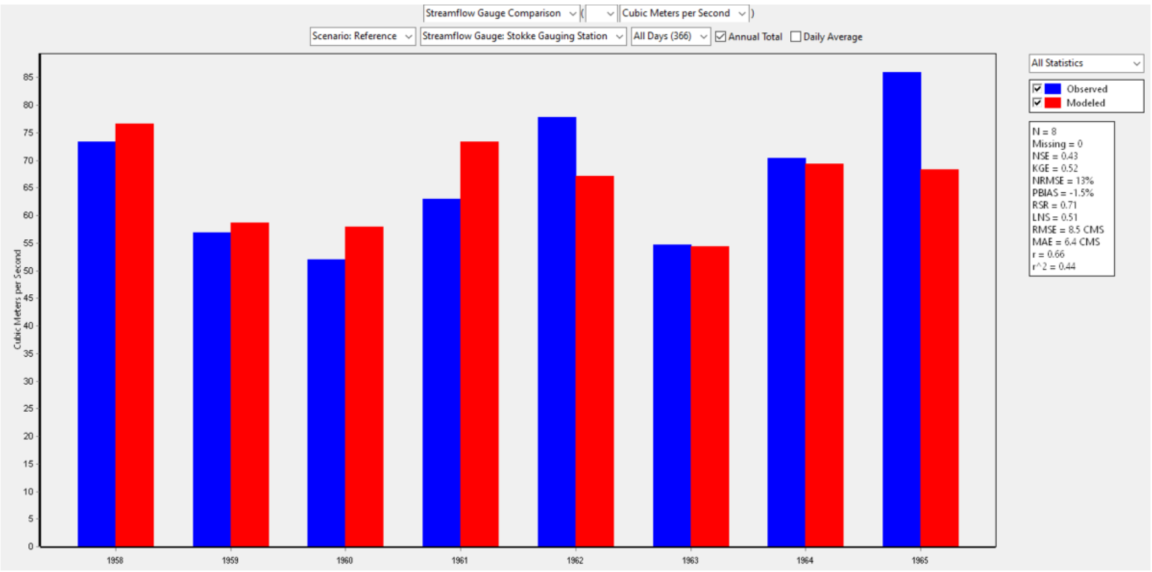
N = 2 922
Missing = 0
NSE = -0.64
KGE = 0.33
NRMSE = 144%
PBIAS = -1.5%
RSR = 1.3
LNS = -0.74
RMSE = 96 CMS
MAE = 54 CMS
r = 0.39
r^2 = 0.15



Streamflow Gauge Comparison ( ) Cubic Meters per Second

Scenario: Reference | Streamflow Gauge: Stokke Gauging Station | All Days (366) | ☐ Annual Total | ☑ Daily Average

N = 366
Missing = 0
NSE = -0.31
KGE = 0.42
NRMSE = 90%
PBIAS = -1.6%
RSR = 1.1
LNS = -0.38
RMSE = 60 CMS
MAE = 38 CMS
r = 0.44
r^2 = 0.2



Streamflow Gauge Comparison ( ) Cubic Meters per Second

Scenario: Reference | Streamflow Gauge: Stokke Gauging Station | All Days (366) | ☑ Annual Total | ☐ Daily Average

N = 8
Missing = 0
NSE = 0.43
KGE = 0.52
NRMSE = 13%
PBIAS = -1.5%
RSR = 0.71
LNS = 0.51
RMSE = 8.5 CMS
MAE = 6.4 CMS
r = 0.66
r^2 = 0.44

Figure 4-4: Comparison of the streamflow for daily step (upper), daily average (middle) and annual totals (lower) variation with observed discharge for Stokke catchment

The streamflow variation at the Stokke gauge is illustrated for the daily results, daily average and the annual total for the calibration period. The PBIAS is kept as low as -1.5%. On the negative note, the peak flow has achieved faster in model simulation than that of the observed discharge in daily average variation. The magnitude of the peak also higher the the observed flood peak. This may be the reason of transferring climate data from adjacent Garbergelva catchment, in which also have an early achive of the peak although the magnitude looks the same. The most possible reason might be existence of regulated flow in the observed discharge of Stokke for the period of 1958-1965. This is further explained in section 5.2.2.

4.2.2 Evaporation

The evaporation results for Stokke model is illustrated below.

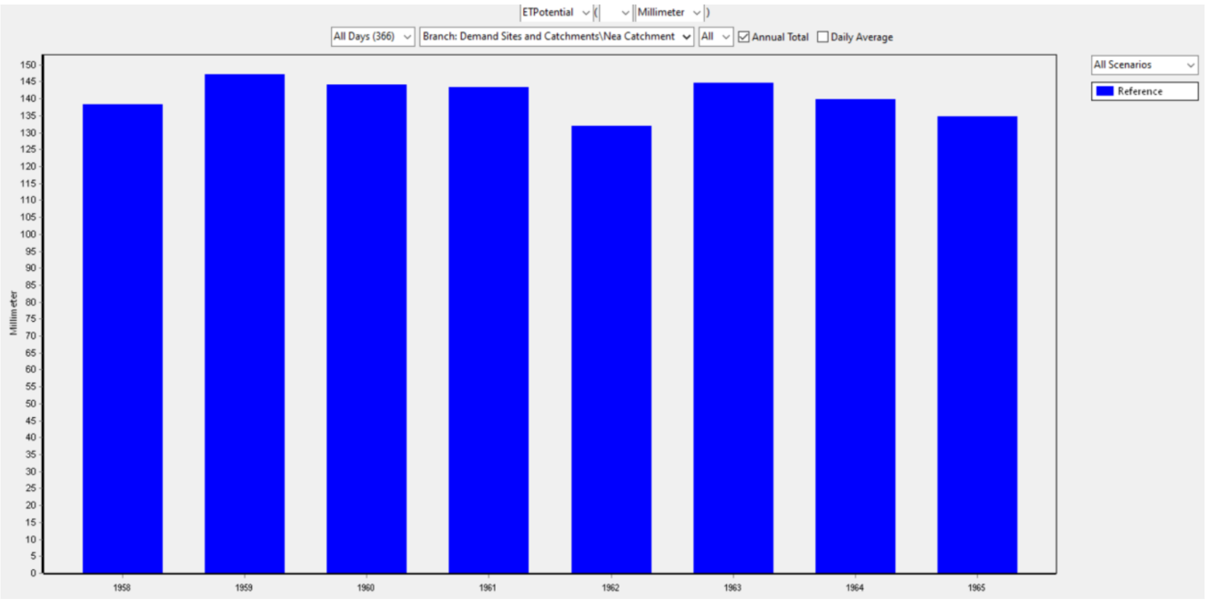
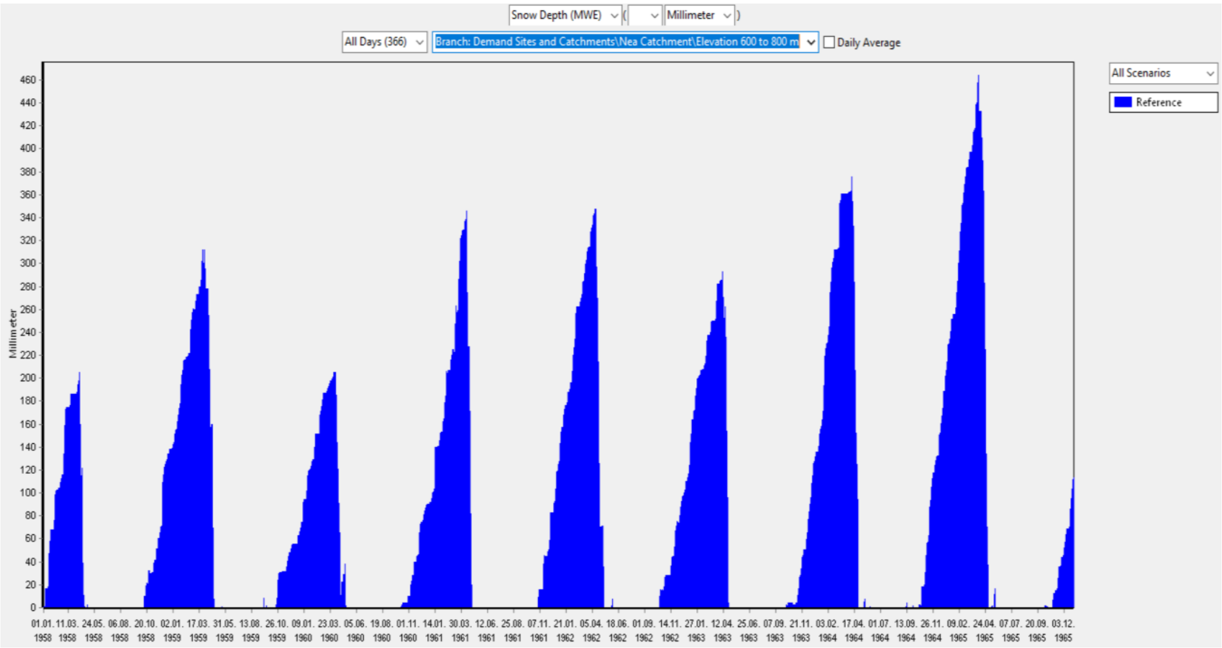


Figure 4-5: Evaporation for Stokke catchment

4.2.3 Snow depth

The Snow depth results for Stokke model is illustrated below. It is represented with respect to the elevation band of 600-800m for the entire period.



Snow Depth (MWE) (Millimeter)

All Days (366) Branch: Demand Sites and Catchments\Nea Catchment\Elevation 600 to 800 m ☐ Daily Average

All Scenarios

Reference

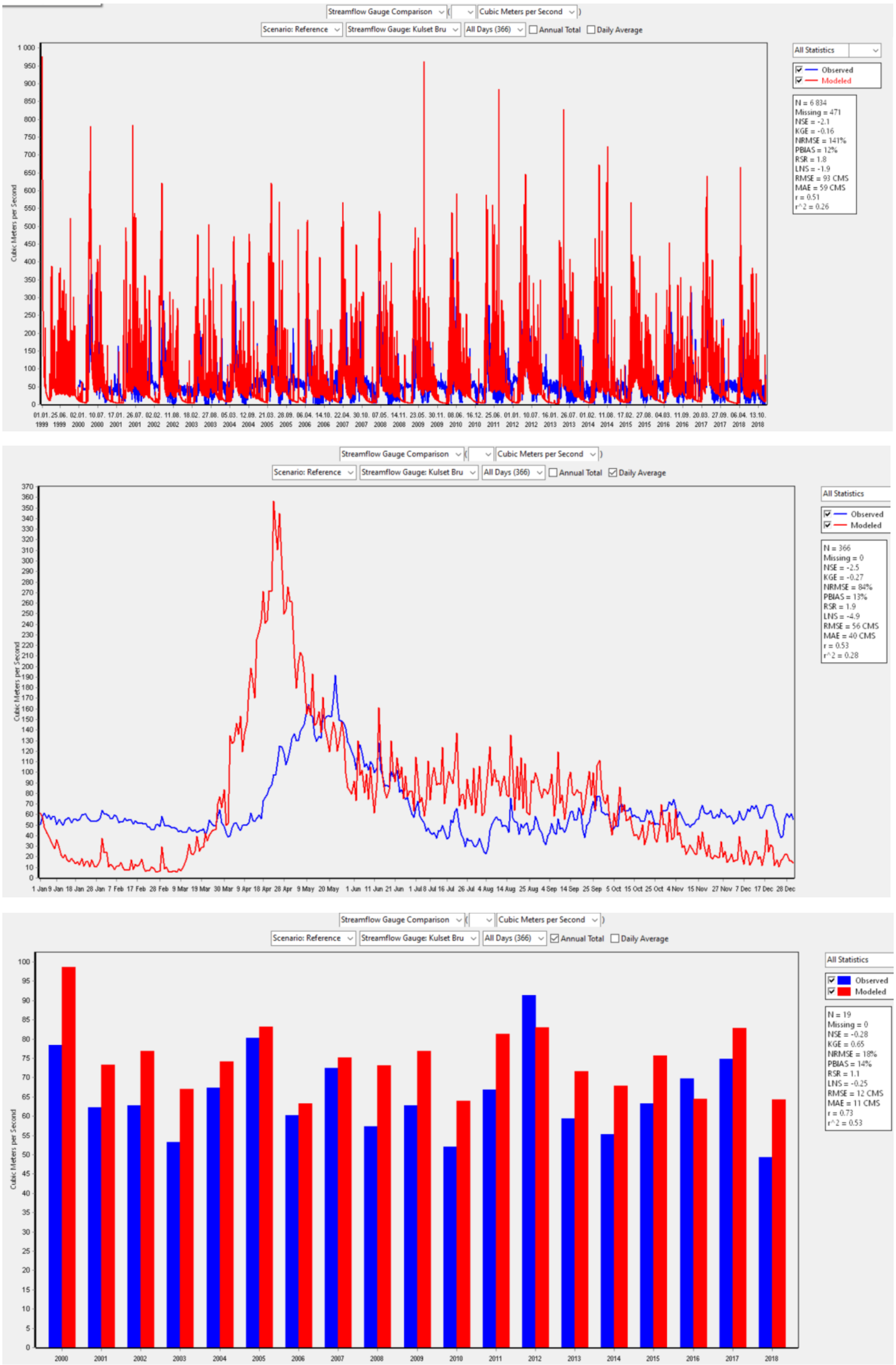
Figure 4-6: Snow depth for Stokke catchment

4.3 Kulset Bru

Kulset model was run for the period of 2000-2018 and analysed the results. The streamflow, snow depth and evaporation of the model was analysed separately.

4.3.1 Streamflow

The same Stokke model was built up as a different model version updating the land area for various elevation bands only. All other land and climate parameters were kept the same as it is in the Stokke model.


Streamflow Gauge Comparison
Cubic Meters per Second
Scenario: Reference
Streamflow Gauge: Kulset Bru
All Days (366)
☐ Annual Total
☐ Daily Average

All Statistics
☑ Observed
☑ Modeled

N = 6 834
Missing = 471
NSE = -2.1
KGE = -0.16
NRMSE = 141%
PBIAS = 12%
RSR = 1.8
LNS = -1.9
RMSE = 93 CMS
MAE = 59 CMS
r = 0.51
r^2 = 0.26

Streamflow Gauge Comparison
Cubic Meters per Second
Scenario: Reference
Streamflow Gauge: Kulset Bru
All Days (366)
☐ Annual Total
☑ Daily Average

All Statistics
☑ Observed
☑ Modeled

N = 366
Missing = 0
NSE = -2.5
KGE = -0.27
NRMSE = 84%
PBIAS = 13%
RSR = 1.9
LNS = -4.9
RMSE = 56 CMS
MAE = 40 CMS
r = 0.53
r^2 = 0.28

Streamflow Gauge Comparison
Cubic Meters per Second
Scenario: Reference
Streamflow Gauge: Kulset Bru
All Days (366)
☑ Annual Total
☐ Daily Average

All Statistics
☑ Observed
☑ Modeled

N = 19
Missing = 0
NSE = -0.28
KGE = 0.65
NRMSE = 18%
PBIAS = 14%
RSR = 1.1
LNS = -0.25
RMSE = 12 CMS
MAE = 11 CMS
r = 0.73
r^2 = 0.53

Figure 4-7: Comparison of the streamflow for daily step (upper), daily average (middle) and annual totals (lower) variation with observed discharge for Kulset bru catchment

4.3.2 Evaporation

The evaporation results for Kulset bru model is illustrated below.

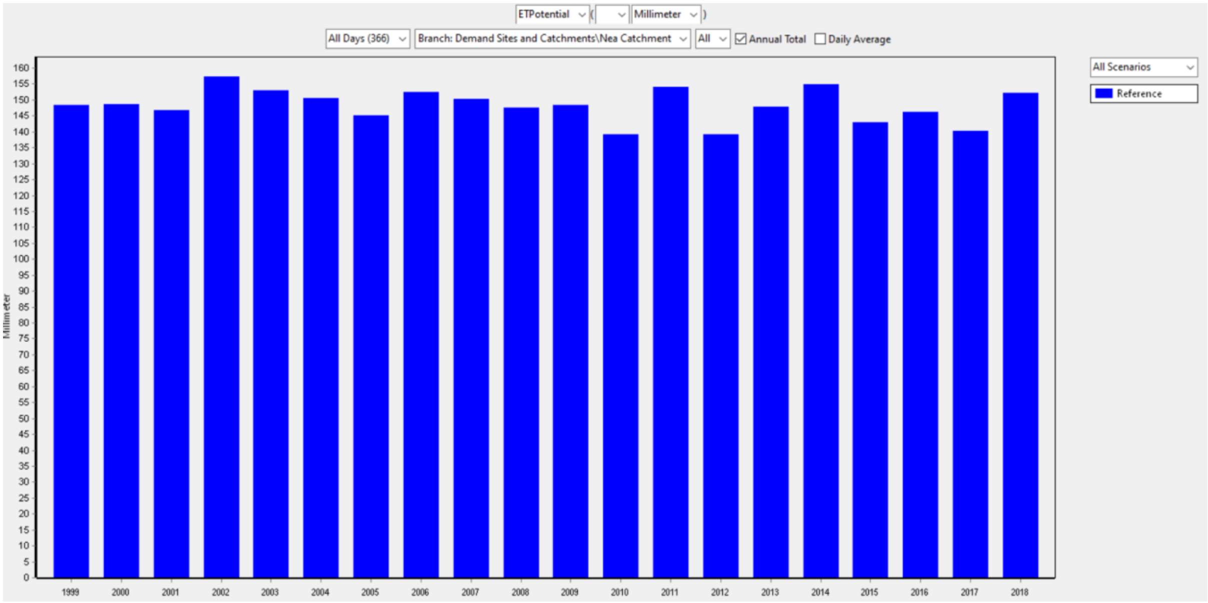


Figure 4-8: Evaporation for Kulset bru catchment

4.3.3 Snow depth

The Snow depth results for Kulset bru model is illustrated below. It is represented with respect to the elevation band of 600-800m for the entire period.

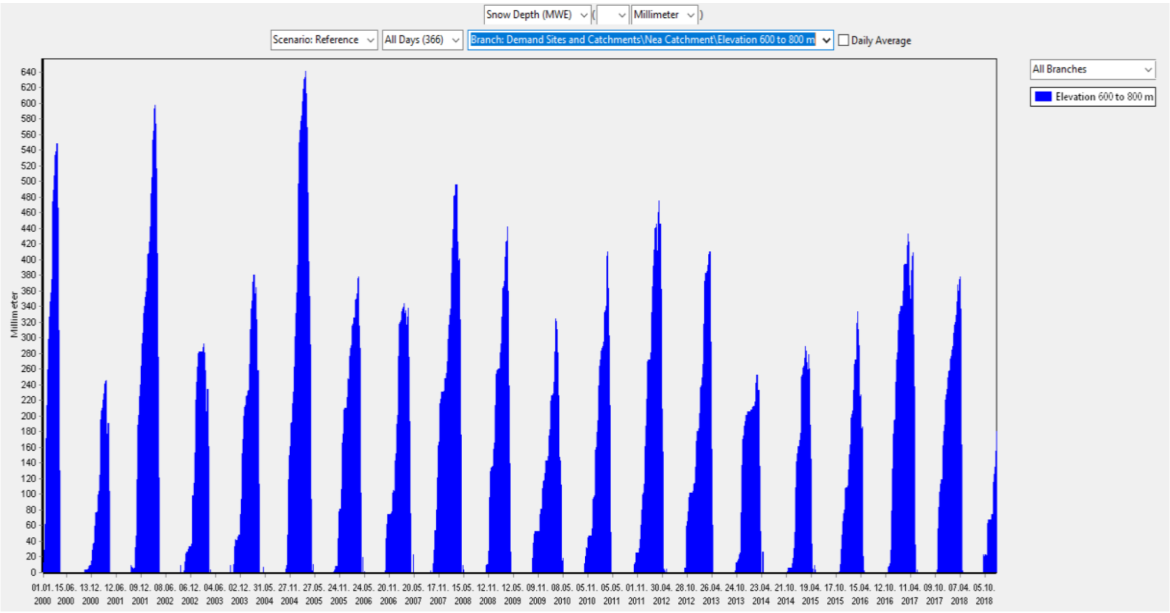


Figure 4-9: Snow depth for Kulset catchment

5 Discussion

This section further explains the results in the Chapter 4.

5.1 Sensitivity of model outputs with variables

The sensitivity of the obtained model outputs is visualized with the parameters in this section. It is necessary to identify the flood scenarios in order to analyse the flood dampening of a study region. Visualization of the flood peak makes a pivotal role in this. Snow depth and evaporation are also important aspects that should be considered in water balance of a hydrological model. Thus, it is vital to analyse simulated streamflow, snow depth and evaporation in WEAP in order asses the suitability of the software in Norwegian climate conditions.

5.1.1 Streamflow

The sensitivity of the climate variables, melting point and freezing point in WEAP was visualized in this section.

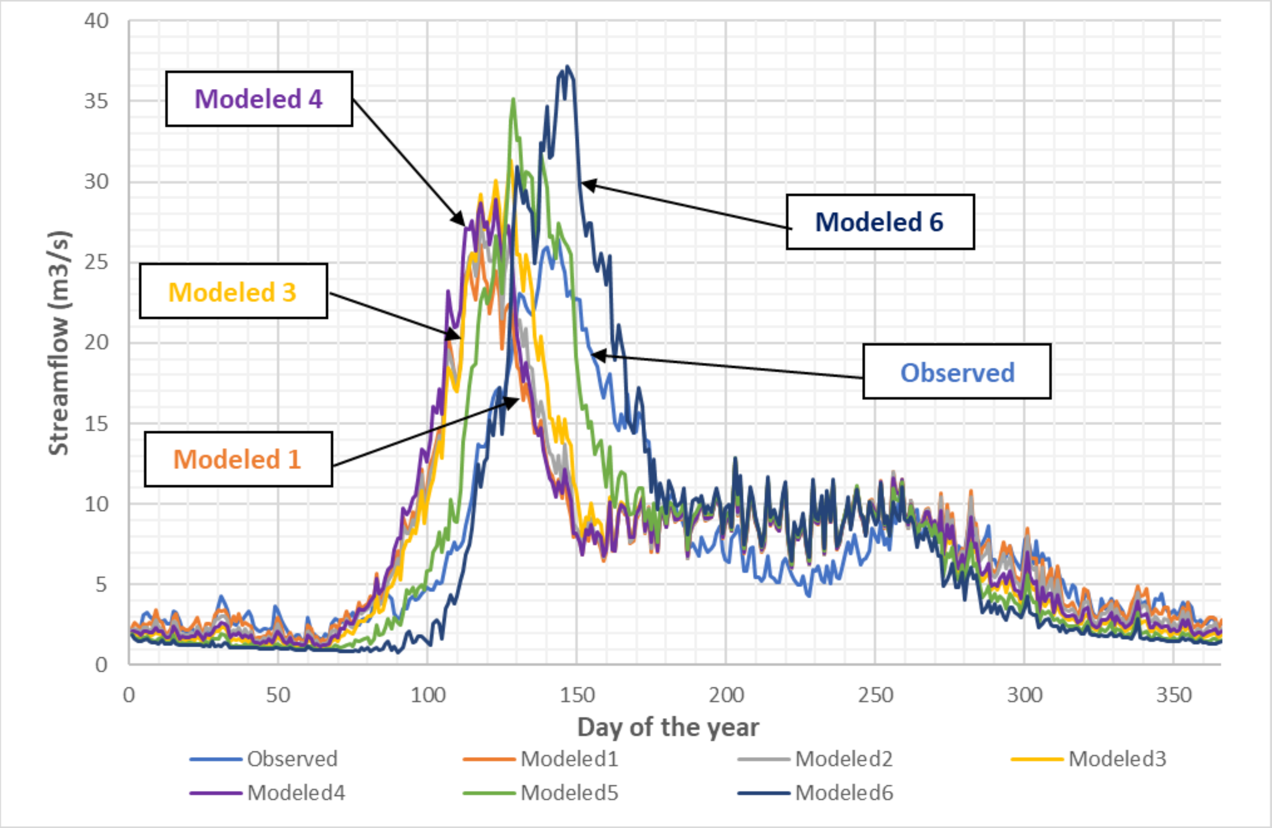


Figure 5-1: Sensitivity of streamflow with climate variables melting point and freezing point

Table 5-1: Climate parameters and discharge values for Model simulations

		Modeled 1	Modeled 2	Modeled 3	Modeled 4	Modeled 5	Modeled 6
Climate Parameters	Melting point (°C)	0.5	2.0	5.0	5.0	5.0	5.0
	Freezing point (°C)	0	0	0	-1.0	2.0	4.0
Discharge	Average Daily (m3/s)	7.54	7.54	7.53	7.53	7.52	7.52

The Figure 5-1 illustrates the variation of the daily average of the streamflow of Garbergelva catchment with regard to the melting point and freezing point of the WEAP model. The PCORR and SCORR was kept at the constant value of 1.5 and 1.15 respectively. The climate variables were changed and observed the variation of the streamflow. The magnitude of peak of spring flood is much higher than that of the autumn flood. Higher deviations can observe in spring flood which occur after the winter season. The peak flood and its volume increase drastically and moves towards right when the freezing point increases from -1°C to 4°C (Modeled 4 to Modeled 6 in the Figure 5-1). On the other hand, when the freezing point is kept constant and melting point increases from 0.5°C to 5°C, there is a slight increase in peak and flood volume, and it shifts a little bit towards right (Modeled 1 to Modeled 3 graphs).

Freezing point in WEAP model is defined as the temperature in which snow accumulation occurs. Melting point is described as threshold of temperature that snow melt commences (Sieber & Purkey, 2015). Increasing the freezing point implies the high possibility of days that snow accumulation occurs. This will delay the snow melt process and more snow will accumulate. Once the temperature is higher than the melting point, a large volume of accumulated snow available and contributes for melting. This results a delayed discharge (by some days) with highly increased flood peak. The average daily discharge hasn’t changed a lot during these adjustments to climate variables (Table 5-1). The analysis helps to understand the variation of streamflow with the climate variables in WEAP throughout the year.

The timing of peak discharge of Modeled6 simulation has a proper match with observed discharge than the other simulations. Additionally, WEAP data tab allows to adjust a range of temperature values from -20°C to 20°C for melting point and freezing point in soil moisture method. However, having a melting point of 5°C and freezing point of 4°C for a catchment is unrealistic. Thus, the calibrated version (Modeled1) in this simulation sticked to a realistic values of melting point and freezing point as 0.5°C and 0°C (value closer to 0°C) respectively.

5.1.2 Evaporation

Evaporation is mainly determined by the Evapotranspiration generated in the WEAP model. This mainly depends on the variables mentioned in the following equation (Yates, Sieber, Purkey, & Huber-Lee, 2005).

$$Evaportranspiration = PET(t)K_{c,j}(t)\left(\frac{5z_{1,j}-2z^{2}{}_{1,j}}{3}\right) \tag{3}$$

PET = The Penman-Monteith value for reference crop potential evapotranspiration

K_c = Crop coefficient

Z1 = Percentage of water with respect to soil water capacity in the top bucket

The crop coefficient depends on the land use type of the catchment. This makes a variety of crop coefficients exist in the study region. The models built for the thesis, was made in a way that the crop coefficients do not vary with respect to the land type. The main reason for that is the complexity of developing and calibration of the hydrological model where data entered manually for each land use category for elevation bands. One crop coefficient was assigned for the entire catchment, and it was adjusted during calibration of the Garbergelva and Stokke WEAP models. The main reason is two basins with no or very little agriculture. So the variation of crop coefficient between the elevation levels will be negligible.

A sensitivity assessment is done for Evapotranspiration potential with regard to crop coefficient of Garbergelva model for 600-800m elevation, which is illustrated by the following Figure 5-2.

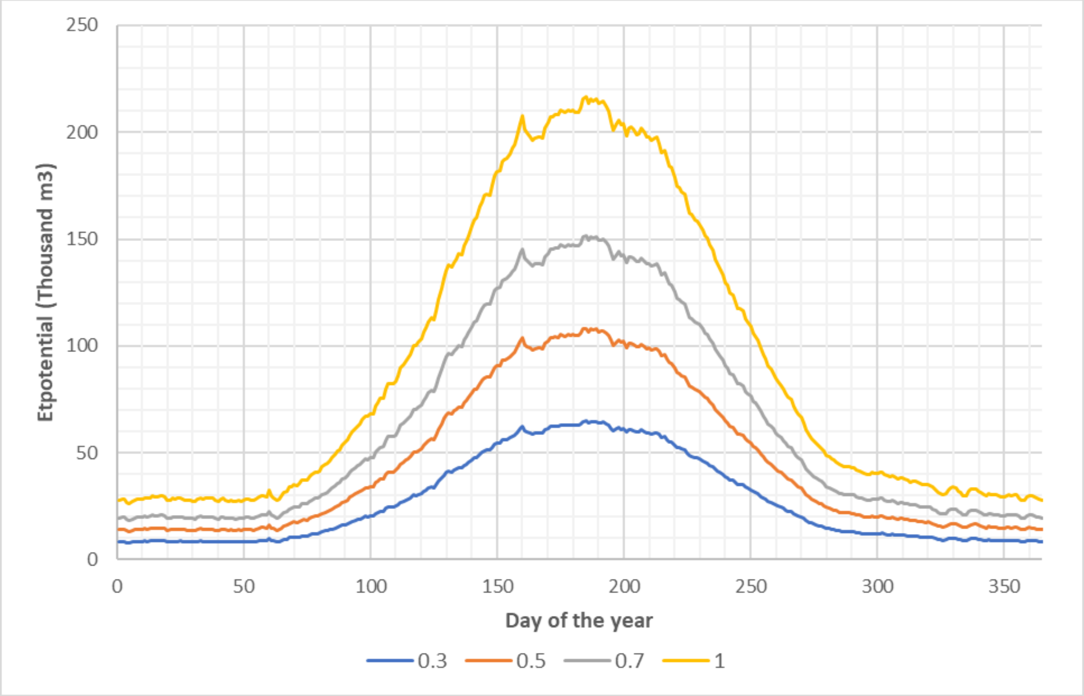


Figure 5-2: Daily average of potential evapotranspiration with respect to crop coefficient

5.1.3 Snow depth

This is the depth of snow that is accumulated in the snowpack of the catchment. It is expressed in Melt Water Equivalent (MWE) depth (Sieber & Purkey, 2015). The equations in the algorithm of Soil moisture method are mentioned below (Yates, Sieber, Purkey, & Huber-Lee, 2005).

$$m_c = \begin{cases} 0;\ T_i < T_s \\ 1;\ T_i > T_l \\ \frac{T_i - T_s}{T_l - T_s};\ T_s \leq T_i \leq T_l \end{cases} \tag{4}$$

m_c = Melt coefficient

T_l = Temperature threshold for melting point

T_s = Temperature threshold for freezing point

T_i = Observed temperature

$$Ac_i = Ac_{i-1} + (1 - m_c)P_i \tag{5}$$

Ac_i = Accumulation of snow

P_i = Observed monthly precipitation

The melt coefficient is less than 1 when the observed temperature in between the thresholds of melting point and freezing point (Equation 4). The snow accumulation higher than the previous instance at this situation (Equation 5). Fewer the temperature gets than the freezing point, higher the snow accumulation occurs (m_c becomes 0). Also, higher the range between the melting point and freezing point becomes, intensity of the snow accumulation decreases. This is tested by running several simulations with variable melting and freezing points.

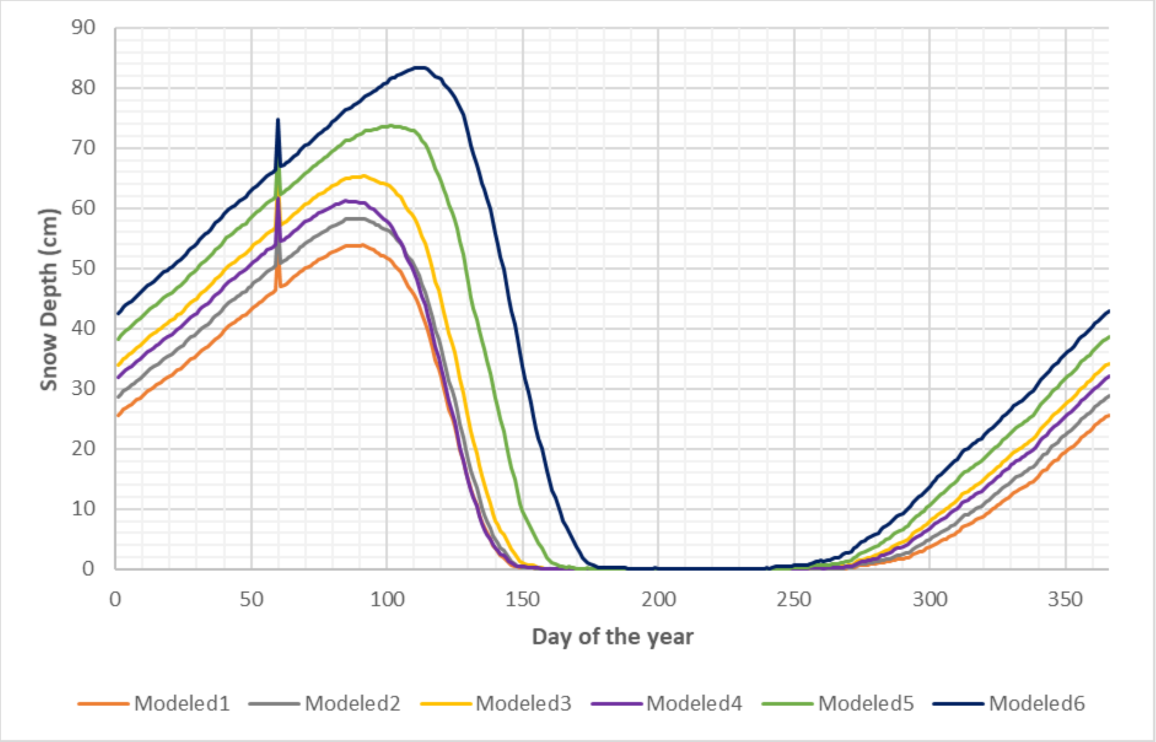


Figure 5-3: Sensitivity of snow depth with climate variables melting point and freezing point

Table 5-2: Climate parameters and snow depth for Model simulations

		Modeled 1	**Modeled 2**	**Modeled 3**	**Modeled 4**	**Modeled 5**	**Modeled 6**
Climate Parameters	Melting point (°C)	0.5	2.0	5.0	5.0	5.0	5.0
	Freezing point (°C)	0	0	0	-1.0	2.0	4.0
Snow depth	Average Daily (cm)	17.47	19.47	22.96	20.70	27.83	33.43

The Figure 5-3 demonstrates the variation of the daily average of the snow deoth with regard to the melting point and freezing point of the WEAP model. The PCORR and SCORR was kept at the constant value as it was in the section 5.1.1. Snow depth increase significantly and remain unmelted for a longer period of time when the freezing point increases from -1°C to 4°C (Modeled 4 to Modeled 6 in the Figure 5-3). On the other hand, when the freezing point is kept constant and melting point increases from 0.5°C to 5°C, there is a slight increase in snow accumulation, and snow available days increase a little bit (Modeled 1 to Modeled 3 graphs). The precipitation input also affects the snow accumulation. Adjusting the correction factors (PCORR & SCORR) has a significant impact in this situation. Variation of PCORR will affect the precipitation of whole period while adjustment in SCORR will alter the rainfall for colder period only.

The parameter Albedo also affects the snow depth in WEAP model. But in this thesis, it was kept constant, and its sensitivity was not analysed. Albedo for the net solar radiation calculation is computed as a broken linear function of snow accumulation and timestep length, ranging in value from Albedo Lower Bound to Albedo Upper Bound. In monthly time step model, it needs much deeper snowpack to achieve the upper bound, which accounts for snow getting older or melting during the month (Sieber & Purkey, 2015).

5.2 Model results with statistics and observations

The model was calibrated using the analysis of various statistics such as NSE, PBIAS, R2. The main statistic that was investigated during the model calibration was PBIAS.

5.2.1 Garbergelva

The calibrated Garbergelva model got a less value for PBIAS. looks The peaks of the daily average for the whole duration achieved quite well with a lag on the timing of the peak can be observed. Setting the climate parameters to the realistic situation (melting point and freezing point as 0.5°C and 0°C) plays a vital role in this scenario (as discussed in section 5.1.1). And also the model was set to the daily time step. So, the regular daily variation was quite observant and it will be difficult to achieve a perfect match with staggering changes of flow. Setting the model to a monthly time step will a slight shift in the original procedure, where the input data (precipitation and temperature) are also added as monthly data. This will be much easier than to calibrate a daily model as rapidly varying flows will be averaged. The streamflow results for 2011 is shown in Figure 5-7.

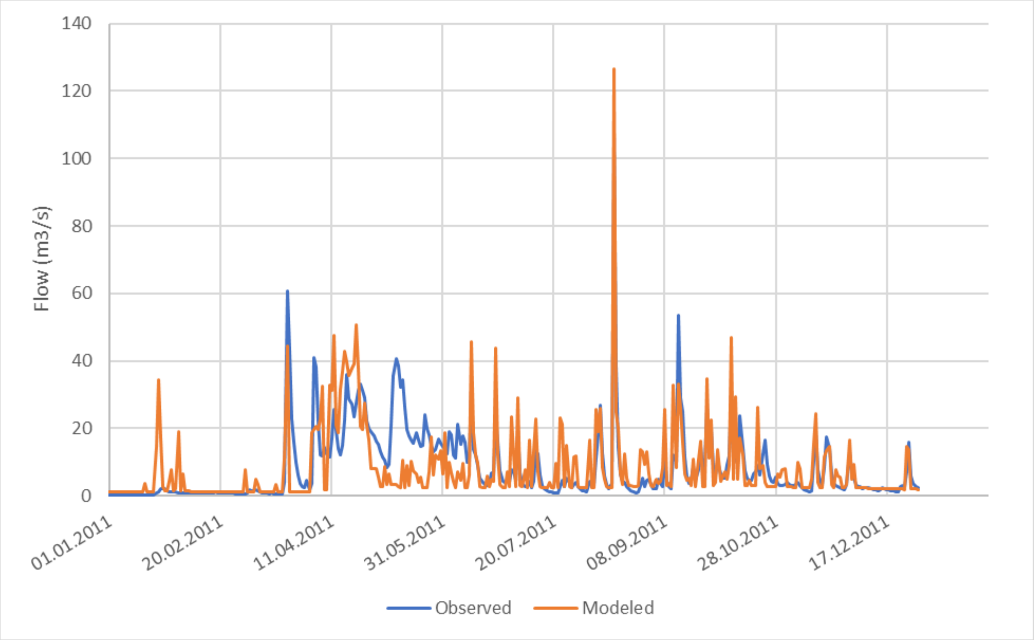


Figure 5-4: The daily variation Streamflow results in 2011 for Garbergelva catchment (observed discharge in blue color whilst simulated flow in orange color)

The R2 (0.5) and NSE (0.37) is quite low as the model couldn’t entirely capture daily variation of the flow. The PBIAS is low as -2.9% which means the difference of volumes of water of simulated and observed flow was not so different. Most of the peaks has captured from July 20th to December 31st.

5.2.2 Stokke

The calibrated Stokke model was done for the period of 1958-1965. Although the major regulations from Nesjøen and Essandsjøen, there is still have the regulation from the Nea power plant (section 2.6.1.2) . There is a definite impact on this to the calibration. The calibrated stoke model PBIAS is good (-1.6%), looking at the daily average results (Figure 4-4), the variation and timing of peaks have not matched properly. This is a clear indication that the observed discharge for the period has an impact on regulations. The daily flow variation for year 1963 is shown in Figure 5-5.

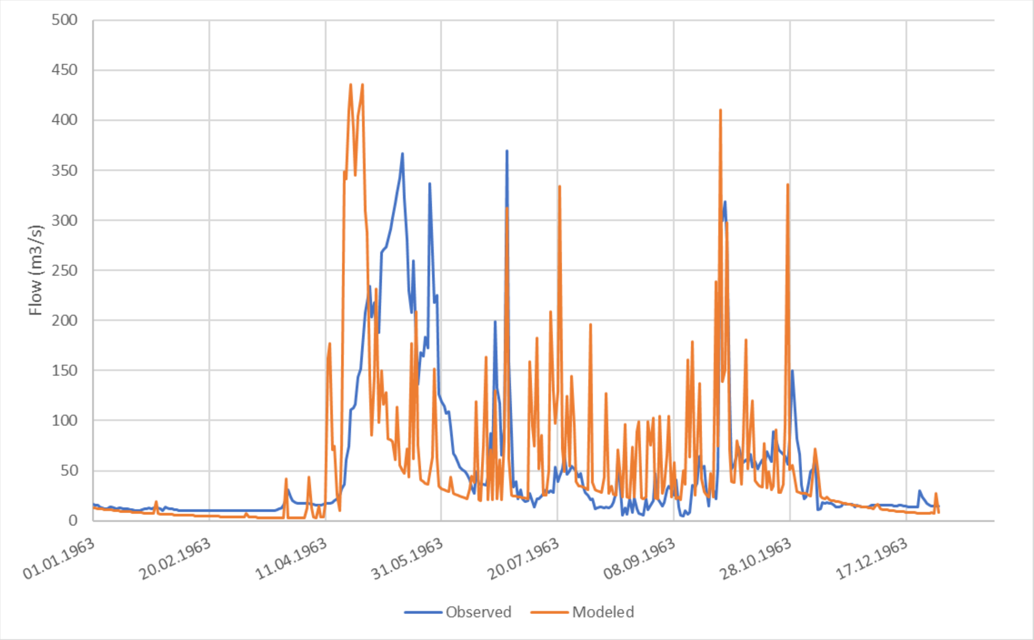


Figure 5-5: The daily variation Streamflow results in 1963 for Stokke catchment (observed discharge in blue color whilst simulated flow in orange color)

The R2 (0.25) and NSE (0.2) is quite low as the model couldn't entirely capture daily variation of the flow. The PBIAS is extremely low as -0.57% which means the difference of volumes of water of simulated and observed flow was not so different. This is maily due to the regulationnof Nea power plant.

5.2.3 Kulset bru

The Kulset bru model was simulated for the period of 2000-2018. Here, it will be compared directly with the regulated observed discharge. The daily variation of streamflow in 2005 is illustrated in Figure 5-6. The highest peaks of flood dampening can be observed in the month of May and July. On the negative note there is some uncertainty of the accuracy of the observed flow in Kulset bru due to the backwater effect of Selbusjøen lake. This will be explained in section 5.4.

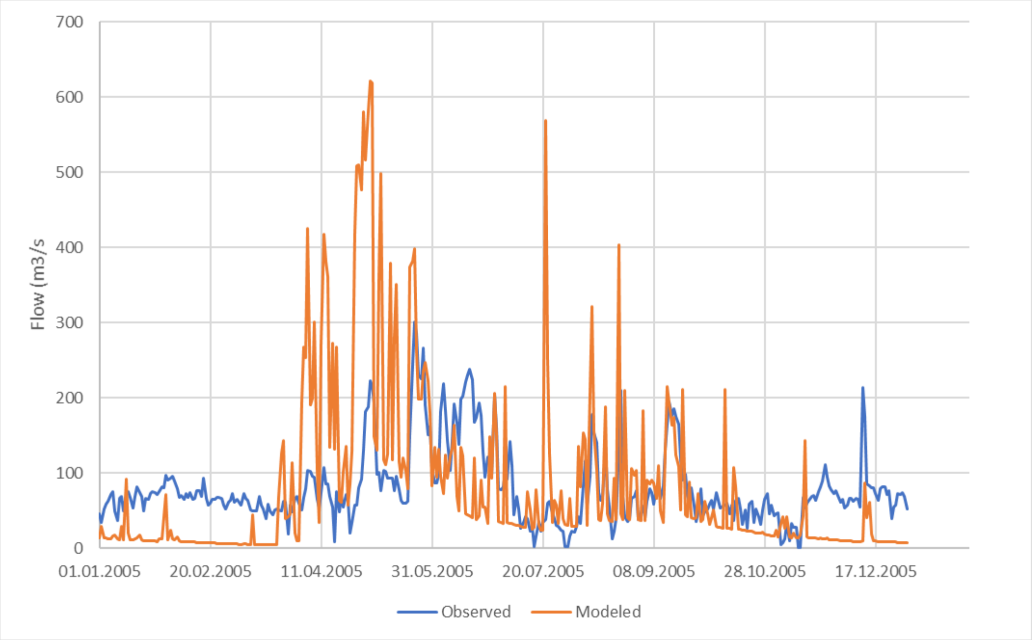


Figure 5-6: The daily variation Streamflow results in 2005 for Kulset bru catchment (observed discharge in blue color whilst simulated flow in orange color)

5.3 Flood Simulations and Flood Dampening

This section covers the main objective of the thesis in which the flood simulations or episodes that highlight the discharge of reservoirs captured from model outputs and observed data. Further, the flood dampening effect of reservoirs in Nea basin is examined.

The streamflow results of Kulset Bru WEAP model is extracted for flood simulations. The model is run from 1957 to 2018 for simulation. The model is built for unregulated state in the Nea catchment in which no reservoirs and its regulations are schematized (section 3.4.3). The results compared with the observed discharge at Kulset bru that depicts the regulated discharge in the downstream of Nea basin.

The annual maximum discharges of the Kulset bru modelled flow (unregulated state) and Kulset Bru gauging station are illustrated in the following bar chart (Figure 21). The period of 1986-1988 and 2000-2018 is analysed considering the data availability of Kulset gauging station.

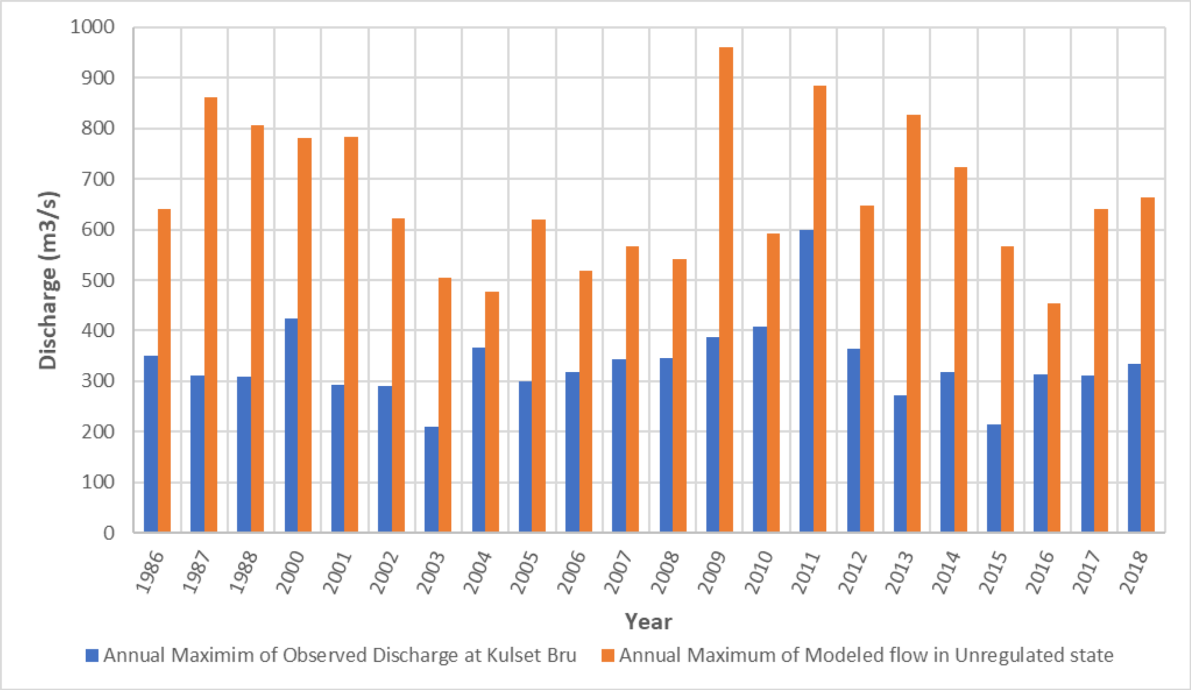


Figure 5-7: Comparison of Annual maximum of modelled flow in the unregulated state (orange bars) and observed discharge (blue bars) at Kulset bru

The unregulated flow in Nea basin is higher than 700m3/s for 8 years, 1987-1988, 2000-2001, 2009, 2011, 2013 and 2014. The maximum unregulated flow found in 2009. A decreasing trend in unregulated discharge is observed for the periods 2000-2008 and 2013-2016. The highest and minimum of annual maximum of observed discharge is represented in 2011and 2003 respectively. Since the most of the flows in Nea basin is observed at the Kulset Bru (most downstream gauge), flood dampening of reservoirs in Nea basin can be depicted by the difference of flood values between unregulated flows and observed discharge (regulated).

Table 5-3: Annual Maximum of Observed discharge (regulated), unregulated modeled flow and flood dampening

Year	Annual Maximum of Observed Discharge at Kulset Bru (m^3/s)	Annual Maximum of Modeled flow in Unregulated state (m^3/s)	Flood dampening (m^3/s)	Flood dampening (%)
1986	351.35	640.23	288.88	45 %
1987	311.26	861.15	549.89	64 %
1988	308.67	807.26	498.59	62 %
2000	423.15	780.73	357.58	46 %

Year	Annual Maximum of Observed Discharge at Kulset Bru (m^3/s)	Annual Maximum of Modeled flow in Unregulated state (m^3/s)	Flood dampening (m^3/s)	Flood dampening (%)
2001	293.31	783.46	490.15	63 %
2002	291.58	621.44	329.86	53 %
2003	210.10	504.51	294.41	58 %
2004	367.08	477.41	110.33	23 %
2005	300.50	620.82	320.31	52 %
2006	318.09	517.34	199.25	39 %
2007	344.42	567.24	222.81	39 %
2008	345.22	541.04	195.81	36 %
2009	387.26	961.09	573.84	60 %
2010	408.02	591.38	183.36	31 %
2011	597.99	883.95	285.96	32 %
2012	364.25	646.60	282.35	44 %
2013	271.10	827.64	556.54	67 %
2014	317.47	722.61	405.14	56 %
2015	215.57	566.51	350.94	62 %
2016	314.08	454.07	140.00	31 %
2017	310.22	639.87	329.65	52 %
2018	333.93	664.46	330.53	50 %

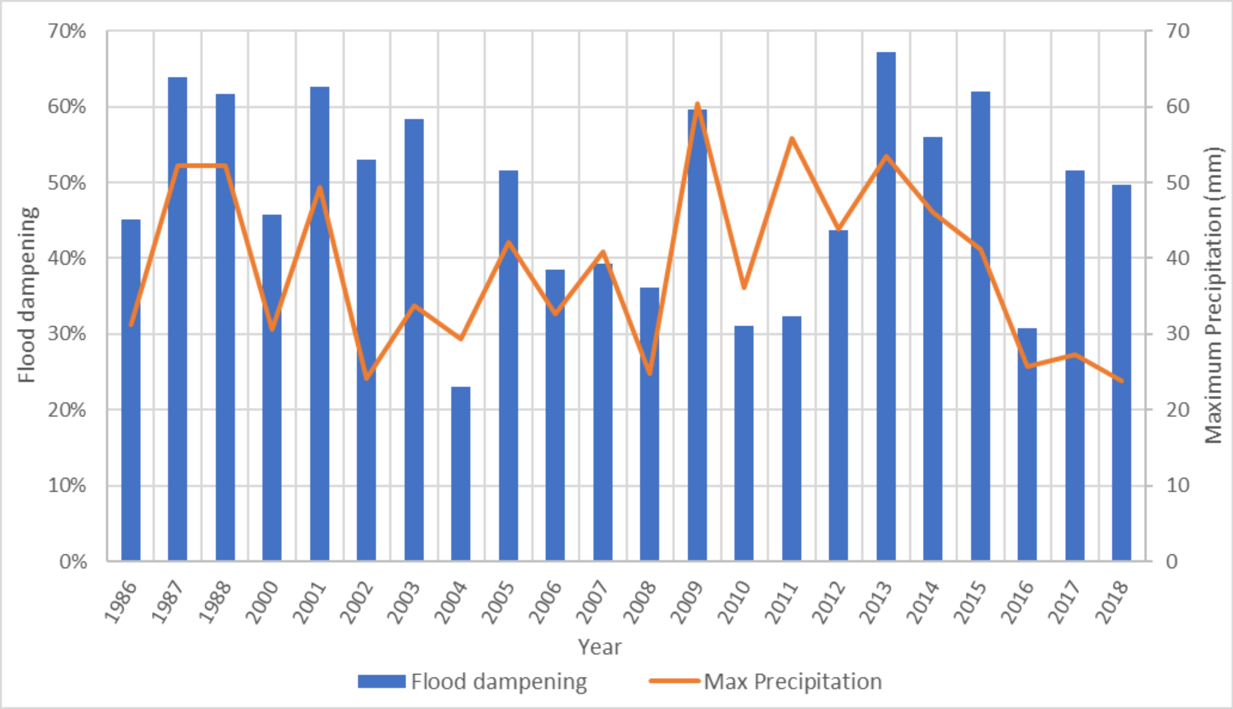


Figure 5-8: Flood dampening (%) and annual maximum precipitation in the center of Nea basin

The flood dampening is calculated in m3/s and as a percentage in the Table …. It is represented graphically as bar chart with the annual maximum precipitation (center of the catchment) in the Figure 5-8. Highest flood dampening is depicted in 2013 whilst the lowest in 2004. The flood dampening appears to be high mostly in wet years (where precipitation is high). Although there are some contradictions related to this in the years 2011, 2017 and 2018. The annual maximum precipitation is high in 2011 although flood dampening is quite less. On the other hand, the dampening of floods are higher in 2017 and 2018 but the precipitation is fairly less. This may be related to the regulations in the Nea basin. Nesjøen is a regulated artificial lake which is the largest lake in the Nea river basin (Vinjar, 2021). The greatest for the water flow conditions in Nea was that Nesjøen was used as a reservoir from 1970 onwards (Pettersson, 2001). Substantial regulations were performed in the years of 2011, 2017 and 2018 according to the reservoir data of Starkraft. These data are not represented in the report due to their confidential agreement.

Seasonal variation of flood dampening was also analysed in this study. It was categorized into Spring flood and Autumn flood seasons.

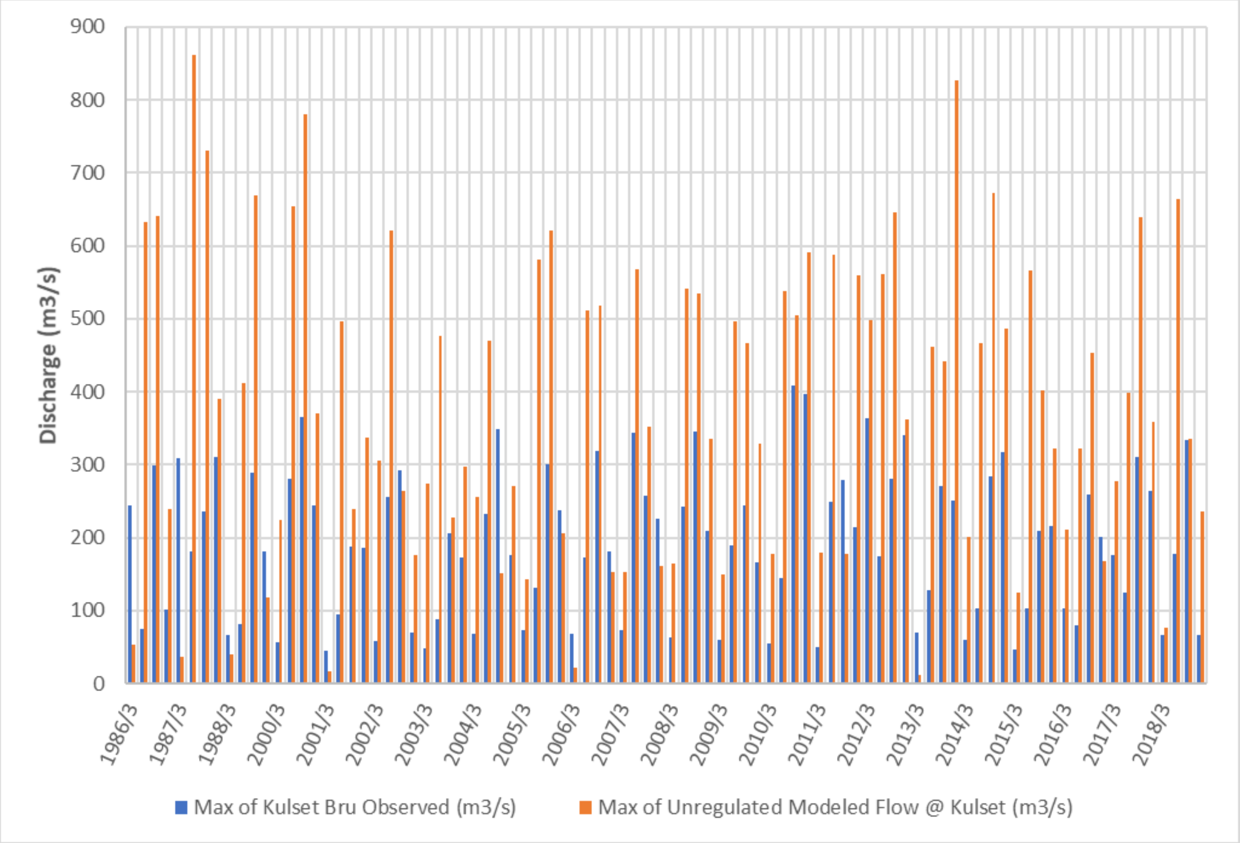


Figure 5-9: Comparison of monthly maximum of modelled flow in the unregulated state (orange bars) and observed discharge (blue bars) in Spring season at Kulset bru

The highest flood dampening is observed in April 1987 and June 2013 whilst the lowest occurred in March 1987 and May 2004 (Figure 5-9). Overall, dampening happened to be larger in the April. The annual maximum for flood dampening (Figure 5-8) has mostly occurred during Spring season.

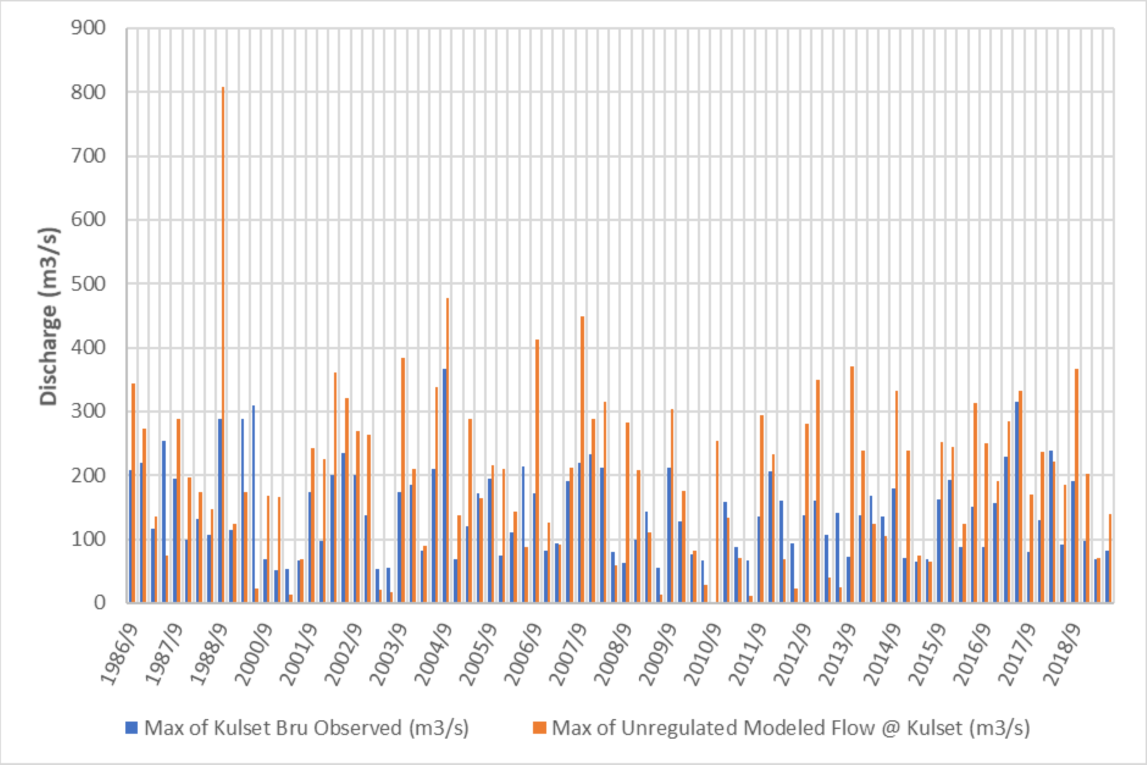


Figure 5-10: Comparison of monthly maximum of modelled flow in the unregulated state (orange bars) and observed discharge (blue bars) in Autumn season at Kulset bru

The highest flood dampening is observed in September of 1988 and 2013 whilst the lowest occurred in December of 1988 and 2005 (Figure 5-10). Generally, dampening happened to be larger in the month of September. A large amount of dampening of floods appeared in 1988 was in Autumn season although the annual maximum for flood dampening (Figure 5-9) has mostly occurred during Spring season.

A report (Pettersson, 2001) about flood calculation for Nea-Nidelvvassdraget was published. The analysis of flood values and flood frequency were carried out in this study as mentioned in section 2.2.2. Flood frequency analysis was done for Stokke gauging station before regulation (1915-1946) and after regulation (1915-1946) in the Nea basin (

Table 5-4). Similar analysis is done for this thesis as well. The unregulated modelled flow and regulated observed discharge at Kulset bru was used for the assessment. The floods for return periods 10, 20, 50, 100, 200, 500 and 100 were calculated using Gumbel method. It was then scaled by multiplying with a factor of 0.985 considering the catchment areas and specific discharges of Stokke and Kulset Bru.

$$\text{Scaling Factor} = \frac{(\text{Catchment area})_{\text{Stokke}} / (\text{Specific Discharge})_{\text{Stokke}}}{(\text{Catchment area})_{\text{Kulset}} / (\text{Specific Discharge})_{\text{Kulset}}}$$

Table 5-4: Flood values for Kuset Bru before regulation (modeled flow) and after regulation (observed discharge) and scaled flood values for stokke

Return Period	Kulset Bru (m^3/s)		Scaled for Stokke (m^3/s)	
	Before Regulation	After Regulation	Before Regulation	After Regulation
10	879.38	438.22	865.79	431.45
20	977.08	482.20	961.98	474.76
50	1103.54	539.14	1086.49	530.82
100	1198.30	581.81	1179.79	572.82
200	1292.72	624.32	1272.76	614.68
500	1417.29	680.41	1395.40	669.90
1000	1511.44	722.80	1488.09	711.63

These scaled flood values were then compared with the flood frequency study for Nea-Nidelvvassdraget.

Table 5-5: Comparison of flood values of study for Nea-Nidelvvassdraget and scaled Stokke

Return Period	(Pettersson, 2001)		Scaled for Stokke (m3/s)	
	Before Regulation (1915-1946)	After Regulation (1970-1989)	Unregulated modelled flow (1957-2018)	Kulset discharge scaled (1986-1988, 2000-2018)
10	891.76	461.69	865.79	431.45
20	985.96	508.87	961.98	474.76
50	1099.00	569.53	1086.49	530.82

Return Period	(Pettersson, 2001)		Scaled for Stokke (m3/s)	
	Before Regulation (1915-1946)	After Regulation (1970-1989)	Unregulated modelled flow (1957-2018)	Kulset discharge scaled (1986-1988, 2000-2018)
100	1174.36	613.34	1179.79	572.82
200	1249.72	657.15	1272.76	614.68
500	1343.92	711.07	1395.40	669.90
1000	1420.08	750.05	1488.09	711.63

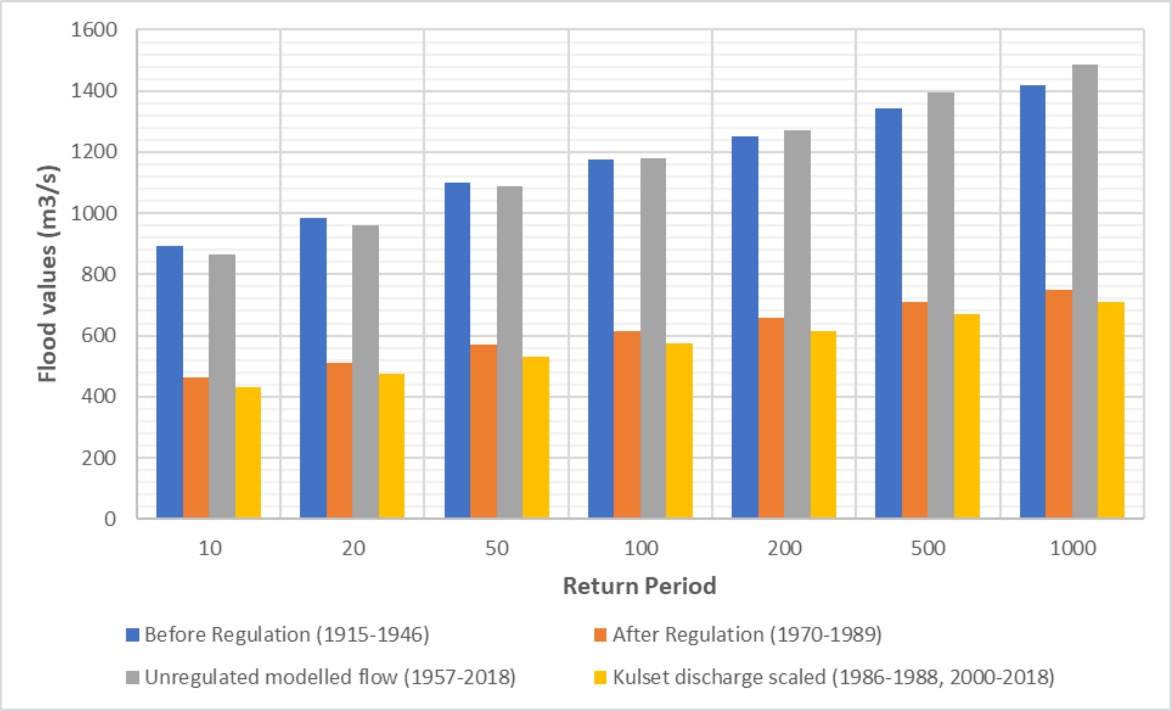


Figure 5-11: Comparison of flood values of study for Nea-Nidelvvassdraget (blue- and orange-coloured bars) and scaled for stoke (grey and yellow coloured bars)

The scaled flood values using EV1 (Gumbel) method, has an average deviation of 4% and -6% for unregulated and regulated conditions in Nea basin with the flood frequency values study for Nea-Nidelvvassdraget in 2001. The GEV method has average deviations of -11% for unregulated state and 15% in regulated state with respect to the study in 2001. Nevina creates a Flood Index Report using regional analysis once a catchment is generated to a specific outlet. This was done for Stokke and -27% average deviation was observed.

There can be many reasons for the deviation of the flood values. Firstly, the time period that the study for Nea-Nidelvvassdraget used was much different to that is used in the thesis. Therefore, the climate can be varied in between these studies. Further, the modelled floods (in WEAP and HBV that is most likely used by NVE), different time periods used in the flood estimates, NEVINA is uncertain when the basins are larger, and maybe more.

5.4 Uncertainty in Kulset bru discharges

The kulset bru gauging station located in the most downstream of the Nea basin (section 2.6.1.3). And it is close to the Selbusjøen lake. When comparing the reservoir level data with observed Kulset data, the discharge of Kulset is highest when the Reservoir level of Selbusjøen Lake is high. During these peak times, there are fluctuations in the reservoir level as well. This can be a backwater effect from Selbusjøen during peak times of Kulset bru. The data got from Starkraft was not presented here due to confidential agreement.

During those events where Selbusjøen is high, the discharges at Kulset bru can be overestimated (due to backwater effects), i.e. and the dampening effect of the reservoirs in the upstream part of the basin under-estimated (sine the discharge at Kulset can be overestimated compared to the true discharge). During those events where Selbusjøen is low and Kulset high, the discharge data at Kulset are probably ok, and the discharge data are correct (and indicate the true dampening effect) without considering modelling or data inaccuracy.

5.5 Comparing PCORR and SCORR with HBV

The precipitation correction and snow correction were applied for all 3 WEAP models, Garbergelva, Stokke and Kulset Bru. The calibrated PCORR and SCORR for these 3 models are compared with the range of correction factors used in HBV.

Table 5-6: Comparison of PCORR & SCORR with WEAP models in this thesis with HBV

	HBV (Killingtveit & Sælthun, Hydrology, 1995)	**Garbergelva**	**Stokke**	**Kulset Bru**
PCORR	1.05 to 1.2	1.5	1.15	1.15
SCORR	1.15 to 1.5	1.15	1.15	1.15

The PCORR and SCORR for the 3 WEAP models is in the range of HBV models according to the source.

6 Conclusion and Limitations

This thesis has assessed the suitability of WEAP for the studies of flood dampening effects of reservoirs in Norway. Three WEAP models were builts for Garbergelva, Stokke and Kulset Bru for unregulated conditions.

It was impossible to directly calibrate the Stokke model by itself due to the limitation of data availibity with involving regulations. So, an adjacent unregulated Garbergelva river basin was selected to set of the WEAP model. Normally, automatic catchment delineation available where automatically download climate, elevation and land use data in WEAP software for certain regions. But it was not available above the Telemark region in Norway. Therefore, schematisation, data addition were to be done manually for the Nea region. The elevation bands were also added manually and data with resprest to that band.

Precipitation and temperature data were gathered from Senorge. Temperature at various elevation bands were gathered since temperature varies with elevation. The gridded precipitation data was multiplied by PCORR and SCORR. After this multiplication only, the simulated streamflow in the model was able to capture Spring and Autumn floods due to the snowmelt. The climate parameters melting point and freezing point played a major role in capturing theses flood peaks. Although the range for these parameters

The highest flood dampening is observed in September of 1988 and 2013 whilst the lowest occurred in December of 1988 and 2005 (Figure 5-10).

There was an uncertainty about the observed flow at Kulset Bru due to the backwater effect in Selbusjøen.

The model was limited to schematizing for unregulated condition of Nea basin.

7 Recommendations

The research analysed the flood dampening effect of Nea basin by developing WEAP model for unregulated condition. It will be interesting to develop the model for regulated condition as well to this basin.

WEAP was unable to allow automatic catchment delineation for regions above Telemark in Norway. This procedure of manually building, schematising, data addition for elevation bands and calibration the model for Norway or similar climate condition where automatic catchment delineation is unavailable.

The WEAP model was build up for Nea basin as a representation of a single cathment. It will be interesting if the Nea basin divided into subcatchments and do the analysis of flood dampening as some characteristics can be varied due to the location of catchment (Upper, middle and lower catchment etc)

8 References

Akan, A. O. (1989). Detention pond sizing for multiple return periods. *Journal of Hydraulic Engineering*, 650-664.

climate change initiative Land Cover. (2015). Tratto da http://maps.elie.ucl.ac.be/CCI/viewer/download.php

de Souza, D. N., de Carvalho Studart, T. M., Lima Neto, I. E., & Beserra Campos, J. N. (2017). Flood damping by reservoirs: proposition of a graphical parametric method. *Revista Brasileira de Recursos Hídricos Brazilian Journal of Water Resources*.

Dove, M. R., & Khan, M. H. (1995). Completing Construuctions of Calamity: The April 1991 Bangladesh Cyclone. *Population and Environment*, 445-471.

Earth Networks. (2022). Tratto da earthnetworks: https://www.earthnetworks.com/flooding/#flood-type

Energi Norge. (2021). Tratto da https://www.energinorge.no/

ENERGY FACTS NORWAY. (2021, May 11). Tratto da https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon/#:~:text=seasons%20and%20years.-,Hydropower,of%20Norways%20total%20power%20production

.

Garcia-Navvaro, P., & Zorraquino, V. (1993). Numerical modeling of flood propagation through system of reservoirs. *Journal of Hydraulic Engineering,*, 380-389.

Glover, B., Sælthun, N., & Walløe, K. (2018). *Verdien av vassdragsreguleringer for reduksjon av flomskader.* Oslo: Multiconsult.

Hansen, B. K. (2018). *Flood dampening in hydropower systems.* Trondheim: NTNU (Norwegian University of Science and Technology).

Heggstad, R. (2017, July 18). *LARGE NORWEGIAN ENCYCLOPEDIA*. Tratto da https://snl.no/Garbergelva

Higgs, G., & Petts, G. (1988). Hydrological changes and river regulation in the UK. *Regulated Rivers: Research and Management*, 349-368.

History. (2009, November 13). Retrieved from https://www.history.com/this-day-in-history/yangtze-river-peaks-in-china

Høydedata. (2021). Tratto da https://hoydedata.no/LaserInnsyn2/

ICOLD. (2020). Tratto da International Commision on Large Dams: https://www.icold-cigb.org/GB/world_register/general_synthesis.asp

Kaushalya, R., & Hemakumara, S. P. (2020). Integration of SWAT and WEAP Models for Water Resource Management in the Malwathu Oya Basin, Sri Lanka. *Resilient Dams for Future* (p. 37-43). Colombo: Sri Lanka National Committee on Large Dams (SLNCOLD).

Killingtveit, Å. (2019). *Flood mitigation by hydropower in Norway*. Trondheim: Norwegian University of Science and Technology (NTNU).

Kvittingen, I. (2020, August 31). *sciencenorway*. Tratto da https://sciencenorway.no/climate-change-environment/historic-amount-of-flooding-in-europe-during-the-last-30-years/1734997

López-Moreno, J., Beguería, S., & García-Ruiz, J. (2002). Influence of the Yesa reservoir on floods of the Aragón River, central Spanish Pyrenees. *Hydrology and Earth System Sciences*, 753–762.

Lugon Junior, J., Tavares, L., Kalas, F., Rodrigues, P., & Wasserman, J. (2019). Reservoir implantation for flood dampening in the Macaé River basin using the Mohid Land model. *CIENCIA NATURA*, 1-10.

Mateo, C. M., Hanasaki, N., Komori, D., Tanaka, K., Kiguchi, M., Champathong, A., . . . Oki, T. (2014). Assessing the impacts of reservoir operation to floodplain inundation by combining hydrological, reservoir management, and hydrodynamic models. *Water Resources Research*, 7245–7266.

Multiconsult. (2021). Tratto da https://www.multiconsult.no/om-oss/kort-om-multiconsult/

NEVINA. (2022). Tratto da https://nevina.nve.no/

Pettersson, L.-E. (2001). *Flood calculation for Nea-Nidelvvassdraget.* Oslo: Norwegian Water Resources and Energy Directorate (NVE).

Public Works Los Angeles Country. (2021). Tratto da https://pw.lacounty.gov/general/faq/index.cfm?48687=48687&Action=getAnswers&FaqID=JSJdXzJRTSAgCg%3D%3D&Keywords=1#:~:text=Answer%3A,the%20following%20weeks%20and%20months.

(2015). *Quick user guide of the Land Cover State products in GTiff and NetCDF formats.* European Space Agency.

Roald, L. A. (2021). *Floods in Norway.* Oslo: NVE.

Schönfelder, L., Bakken, T., Alfredsen, K., & Adera, A. (2017). *Application of HYPE in Norway.* Trondheim: SINTEF Energy Research.

Seriekart. (2021). Tratto da https://seriekart.nve.no/

Sieber, J., & Purkey, D. (2015). *USER GUIDE for WEAP*. Somerville: Stockholm Environment Institute (SEI).

statista. (2021). Tratto da https://www.statista.com/statistics/1045048/number-of-hydro-power-stations-in-norway-by-size/

Statkraft. (2021). Tratto da https://www.statkraft.com/what-we-do/hydropower/

Tena, T. M., Nguvulu, A., Mwelwa, D., & Mwaanga, P. (2021). Assessing Water Availability and Unmet Water Demand Using the WEAP Model in the Semi-Arid Bweengwa, Kasaka and Magoye Sub-Catchments of Southern Zambia. *Journal of Environmental Protection*, 280-295.

The Explorer. (2020, October). Tratto da https://www.theexplorer.no/stories/energy/renewable-energy-flows-through-norway/

Vinjar, A. (2021, April 12). *LARGE NORWEGIAN ENCYCLOPEDIA*. Tratto da Store norske leksikon: https://snl.no/Nesj%C3%B8en

Vinjar, A., & Rosvold, K. A. (2021, April 12). *LARGE NORWEGIAN ENCYCLOPEDIA*. Tratto da Store norske leksikon: https://snl.no/Neavassdraget

Wikipedia. (2019, December 15). Tratto da https://en.wikipedia.org/wiki/Nea_River

Wikipedia. (2022, April 5). Tratto da https://en.wikipedia.org/wiki/1938_Yellow_River_flood

Wikipedia. (2022, April 11). Tratto da https://en.wikipedia.org/wiki/WEAP

Yang, L., Liu, M., Smith, J. A., & Tian, F. (2017). Typhoon Nina and the August 1975 Flood over Central China. *Journal of Hydrometeorology*, 451–472.

Yates, D., Sieber, J., Purkey, D., & Huber-Lee, A. (2005). WEAP21—A Demand-, Priority-, and Preference-Driven Water Planning Model. *Water International*, 487-500.